REPORT No. 510

WIND-TUNNEL RESEARCH COMPARING LATERAL CONTROL DEVICES PARTICULARLY AT HIGH ANGLES OF ATTACK

XIII—AUXILIARY AIRFOILS USED AS EXTERNAL AILERONS

By Fred E. Weick and Richard W. Noyes

SUMMARY

This is the thirteenth report on a series of systematic tests comparing lateral control devices with particular reference to their effectiveness at high angles of attack. The present tests, conducted in the N. A. C. A. 7- by 10-foot wind tunnel, were made to determine the most feasible locations for lateral control surfaces mounted externally to a rectangular Clark Y wing.

Two sets of external ailerons were used. One had an N. A. C. A. 0012 symmetrical profile and a chord length that was 15 percent of the main wing chord. The other set of ailerons, which was used at only a few test positions, had an N. A. C. A. 22 cambered profile and a chord length of 14.5 percent of the main wing chord. Both ailerons extended over the full span of the main wing and were hinged about an axis on their chord line 20 percent from their leading edge. The range of positions investigated was from 27 percent of the main wing chord ahead of the leading edge of the main wing to 10 percent behind the trailing edge and from 40 percent above the chord to 20 percent below the chord.

In each position tested full advantage was taken of any improvement in the performance characteristics of the main wing that was possible to be obtained by special use of the ailerons. Thus, at positions close to the leading edge, where the air loads were suitable, the ailerons were mounted so as to act as automatic slats. Likewise, at positions near the trailing edge the ailerons were arranged to function as flaps in addition to being lateral control surfaces.

The results of the wind-tunnel tests showed that no location tested for external ailerons was entirely satisfactory with respect to both performance and control. The best locations tested lay in a region between the leading edge and 30 percent of the chord back from the leading edge, and from 3 to 9 percent above the upper surface. Choice of a particular location depends on a compromise between good performance, obtainable near the leading edge, and good control, obtainable near the rear of the favorable region.

If it is desirable to use the ailerons as flaps in addition to their function as lateral control devices, the best position lies 2$^1/_2$ percent of the chord behind and 2$^1/_2$ percent below the trailing edge of the main wing.

Flight tests made with external ailerons in one of the positions over the forward part of the wing showed serious practical difficulties due to heavy hinge moments and irregular control-force variation.

INTRODUCTION

A series of systematic wind-tunnel investigations, one of which is covered by this report, has been made by the National Advisory Committee for Aeronautics in order to compare various lateral control devices. The various devices were given the same routine tests to show their relative merits in regard to lateral control and, to some extent, their effect on the lateral stability and the performance of an airplane. They were all tested on rectangular Clark Y wings of aspect ratio 6, and a few of them have been further tested on wings with different plan forms and wings with high lift devices. The first report of this series (reference 1, pt. I) dealt with three sizes of ordinary ailerons; one of these was taken from the average of a number of conventional airplanes and was used as the standard of comparison throughout the entire investigation. Other work that has been done in this series is reported in reference 1, parts II to XII.

The present report covers an investigation to determine the most favorable location for external ailerons relative to a rectangular monoplane wing. The term "external aileron" is here defined as any lateral control surface wholly and permanently external to the main wing profile. The survey of possible locations was made mainly with an N. A. C. A. 0012 symmetrical airfoil having a chord 15 percent of the main wing chord and a span equal to that of the main wing. The airfoil was hinged about a point 0.2 of its chord back from its leading edge and was divided at the center of the span to allow differential settings of the two halves. The ailerons were tested in the 48 positions shown in figure 1 as fixed surfaces relative to the main wing and as connected but freely floating ailerons in certain positions where it seemed that such an arrangement might be desirable. In a few positions both the symmetrical airfoil and the highly cambered N. A. C. A. 22 airfoil were tested, and at two positions just above the trailing edge tests were made on only the N. A. C. A. 22 airfoil. Flight tests were conducted with external ailerons in two of the most interesting positions near the leading edge.

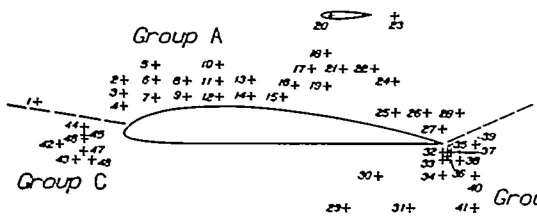


FIGURE 1.—External aileron test positions. Crosses indicate the location of the aileron axis (20 percent of the aileron chord from its leading edge).

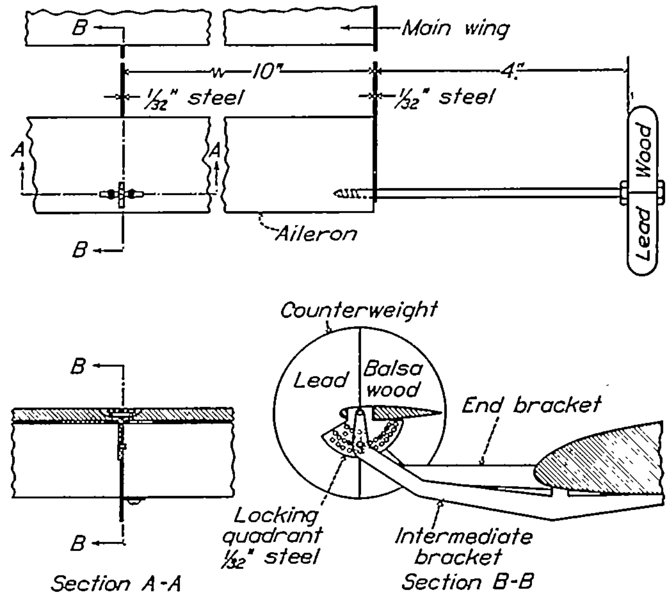


FIGURE 2.—External aileron mounting details.

TABLE I

AIRFOIL ORDINATES, ALL VALUES IN PERCENT AIRFOIL CHORD

Clark Y			N. A. O. A. 22			N. A. O. A. 0012		
Station	Upper surface	Lower surface	Station	Upper surface	Lower surface	Station	Upper surface	Lower surface
0	3.50	3.50	0	2.88	2.88	0	0	0
1.25	5.45	1.93	1.25	5.40	1.09	1.25	1.89	1.89
2.5	6.50	1.47	2.5	6.48	.65	2.5	2.62	2.62
5	7.90	.93	5	8.02	.28	5	3.56	3.56
7.5	8.85	.63	7.5	9.11	.08	7.5	4.20	4.20
10	9.60	.42	10	9.96	0	10	4.68	4.68
15	10.68	.15	15	11.34	.12	15	5.34	5.31
20	11.36	.03	20	12.29	.44	20	5.74	5.74
30	11.70	0	30	13.35	1.46	30	6.00	6.00
40	11.40	0	40	13.42	3.08	40	5.80	5.80
50	10.52	0	50	12.60	4.78	50	5.29	5.20
60	9.15	0	60	11.12	5.63	60	4.56	4.56
70	7.35	0	70	9.15	5.79	70	3.66	3.66
80	5.22	0	80	6.68	4.68	80	2.62	2.62
90	2.80	0	90	3.95	2.67	90	1.45	1.45
95	1.49	0	95	2.51	1.32	95	.81	.81
100	.12	0	100	1.13	0	100	.13	.13
Leading-edge radius=1.50			Leading-edge radius=2.00			Leading-edge radius=1.58		

APPARATUS

Model.—The model used throughout this investigation was a laminated mahogany Clark Y airfoil having a 10-inch chord and a 60-inch span, to which were attached duralumin external ailerons extending over the entire span of the main wing. Two sets of external ailerons were used in the course of the tests; one set consisted of 1.50-inch chord, N. A. C. A. 0012 airfoils, and the other of 1.45-inch chord, N. A. C. A. 22 airfoils. The latter set of ailerons had been previously used in the tests reported in references 2 and 3 as the auxiliary airfoil. The ordinates of the main wing and the two ailerons are given in table I.

Figure 2 illustrates the method of mounting the ailerons in position 1. The arrangement for mounting in any of the other positions differed from that shown only in the design of the supporting brackets.

The ailerons were supported by seven steel brackets (see fig. 3) in such a manner that they could be rotated in pitch about an axis intersecting the mean camber line at 0.2 of the aileron chord from its leading edge. When arranged to float, the ailerons were locked together at the center and a counterweight of the type shown in figure 2 was attached to each tip to balance the system statically. Preliminary tests showed that the distance from the wing tip to the counterweight indicated on figure 2 was sufficient to eliminate any noticeable interference effects on the wing.

When the ailerons were mounted so as to remain at a fixed angle relative to the main wing, the counterweight shaft was replaced by a screw (see fig. 3) and locking screws clamped the locking quadrants (fig. 2) to the supporting brackets. The angular interval between holes in the quadrant was 5°.

Wind tunnel.—All the present tests were made in the N. A. C. A. 7- by 10-foot open-jet wind tunnel. In this tunnel the model is supported in such a manner that the forces and the moments about the quarter-chord point of the midsection of the model are measured directly in coefficient form. For autorotation tests the standard force-test tripod is replaced by a special mounting that permits the model to rotate about the longitudinal wind axis passing through the midspan quarter-chord point. This apparatus is mounted on the balance, and rolling-moment coefficients can be read directly during forced-rotation tests. A complete description of the above-mentioned equipment is given in reference 4.

All measurements of forces and moments on the wing model were obtained from the 6-component balance in the form of the absolute coefficients (lift, C_L; drag, C_D; rolling moment, C_l'; yawing moment, C_n'; and pitching moment about the quarter-chord point, $C_{m_{c/4}}'$). The coefficients in all cases were based upon the total wing area and were not corrected for tunnel-wall effect. The center-of-pressure location is given in percentage of the main wing chord.

The investigation covered 48 positions for the aileron axis as given in table II. In general, the tests at each position were divided into four main subdivisions, as discussed in the following paragraphs. The extent to which the tests were carried out in detail depended upon the importance of the position in question.

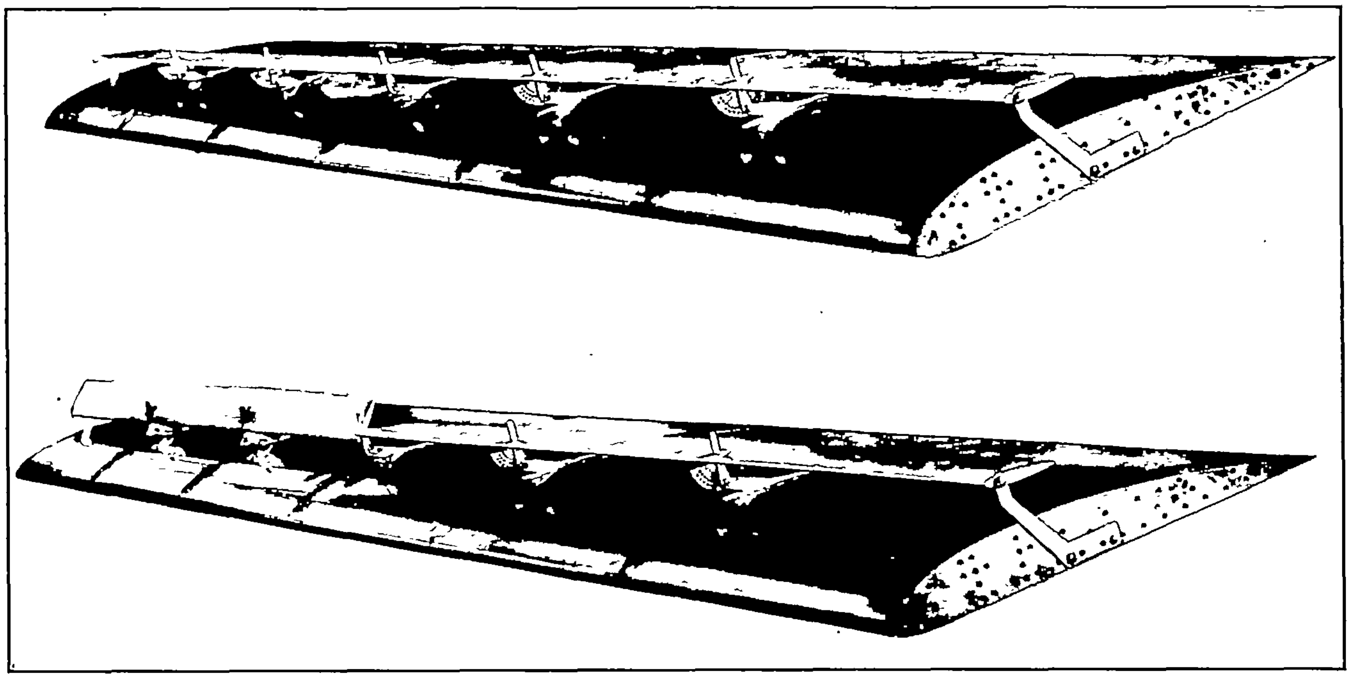


FIGURE 3.—Wing model with external ailerons mounted in position 6.

TESTS AND RESULTS

The tests were conducted in accordance with the standard procedure and at the dynamic pressure and Reynolds Number employed throughout the entire series of investigations on lateral control (reference 1). The dynamic pressure was 16.37 pounds per square foot, corresponding to an air speed of 80 miles per hour at standard density; and the Reynolds Number, based on the chord of the main wing, was approximately 609,000.

(1) Preliminary tests.—Preliminary force tests were made at each aileron position to determine the best angular settings of the ailerons (when neutral) for maximum lift and minimum drag. From the results of these tests neutral angles were chosen for the subsequent tests and the most favorable method of using the ailerons as an aid to the general performance characteristics of the main wing was decided upon. Thus, the ailerons in all the positions shown in group A were found to be most efficient when held fixed at an optimum angle at which were obtainable the best values of both $C_{L_{max}}$ and $C_{D_{min}}$. Similarly, in group B best performance was attained by using the ailerons as flaps. In group C the maximum value of the lift coefficient and the minimum value of the drag coefficient were best obtainable by allowing the ailerons to float

between stops that limited their travel to the critical angles giving the above-mentioned characteristics.

Aileron positions lying beneath the central part of the main wing were not tested, because the extreme positions in regions B and C showed generally poor performance and control characteristics. It is to be expected, however, that if the ailerons were placed at a sufficient distance from the lower surface of the main wing to avoid adverse interference effects, more satisfactory results might be obtained.

(2) Performance characteristics.—The measurement of the performance characteristics included the determination of $C_{D_{min}}$, C_D at $C_L=0.70$ (climb criterion), $C_{L_{max}}$, and the complete lift and drag curves up to $\alpha=40°$. At the aileron positions in group A these tests were made with the ailerons set at the single, optimum, neutral angle found in the preliminary tests. At all the positions in group B the neutral angle chosen corresponded to that giving best climb. In the more important positions, however, tests were also made with ailerons in the high-lift and the low-drag attitudes. In group C the tests were made with the ailerons floating between stops as described in the preceding paragraph.

Tests in which the ailerons were allowed to float were attempted in region B but, because the ailerons exhibited a tendency to flutter, complete runs were made at only a few positions. The effect on this tendency of changes in the axis location or in the friction and elasticity of the supporting and balancing systems is likely to be critical; hence any conclusions regarding the possibility of ailerons fluttering in this region are not warranted. Values of $C_{L_{max}}$ and the ratio $C_{L_{max}}/C_{D_{min}}$ were decreased and C_l' was increased at low angles of attack by allowing the ailerons to float.

(3) Control effectiveness.—The tests to determine the control effectiveness of the ailerons in the various positions were made with the ailerons deflected one at a time—the right aileron with its trailing edge up and the left aileron with its trailing edge down. In all the

TABLE II

AILERON DEFLECTIONS FOR DATA GIVEN IN FIGURES 4 TO 19

[Aileron axis, 20 percent from L. E. of aileron
Aileron axis coordinates: (+) Above chord and back of L. E. (−) Below chord and ahead of L. E.]

Region	Position	Aileron axis position		Neutral aileron angles			Maximum angle of deflection		Limit of deflection	
		Percent chord from L. E.	Percent chord from chord	Low drag	Maximum $\frac{L}{D}$ at $C_L=0.70$	High lift	Up	Down	Up	Down
				Degrees	Degrees	Degrees	Degrees	Degrees		
	1	−27	13	0	0	0	−5	50	Optimum	Fixture.
	2	0	20	−5	−5	−5	−60	40	Fixture	Do.
	3	0	16	−10	−10	−10	−70	32	do	Wing.
	4	0	12	−10	−15	−20	−55	5	do	Do.
	5	10	25	0	0	5	−75	50	do	Fixture.
	6	10	20	0	0	0	−50	48	do	Wing.
	7	10	15	−5	−5	−5	−70	17	do	Do.
	8	20	20	0	0	0	−60	40	do	Do.
	9	20	15	0	0	0	−70	15	do	Do.
	10	30	25	5	5	5	−75	50	do	Fixture.
	11	30	20	5	5	5	−60	40	do	Wing.
	12	30	15	5	5	5	−70	----	Wing	Do.
	13	40	20	10	10	10	−60	40	Fixture	Do.
	14	40	15	5	5	5	−70	22	do	Do.
A	15	50	15	10	10	10	−70	----	do	Do.
	16	53.75	18.75	10	10	10	−60	15	do	Optimum.
	17	58.75	23.75	10	10	10	−60	15	do	Do.
	18	63.75	28.75	10	10	10	−55	20	do	Do.
	19	63.75	18.75	10	10	10	−60	15	do	Do.
	20	65	40	5	5	5	−65	10	do	Do.
	21	63.75	23.75	10	10	10	−60	15	do	Do.
	22	78.75	23.75	10	10	10	−60	15	do	Do.
	23	85	40	5	5	5	−65	15	do	Do.
	24	85	20	10	10	10	−60	20	do	Do.
	25	85	10	15	15	15	−50	----	Optimum	
	26	95	10	10	10	10	−60	20	Fixture	Optimum.
	27	100	5	2.5	2.5	2.5	−30	24	Optimum	Do.
	28	105	10	10	10	10	−60	30	Fixture	Do.
	29	70	−20	0	0	30[1]	−20	40	Optimum	Fixture.
	30	80	−10	0	0	30[1]	−10	40	do	Do.
	31	90	−20	0	0	30[1]	−20	40	do	Optimum.
	32	100	−2.5	----	----	45	----	----	----	
	33	100	−5	0	10	50	−10	50	Optimum	Fixture.
	34	100	−10	0	0	15	−10	50	do	Do.
B	35	101.25	−2.5	−5	10	45	−10	50	do	Optimum.
	36	101.25	−3.75	----	----	50	----	----	----	
	37	102.5	−2.5	−5	10	25	−20	30	Optimum	Optimum.
	38	105	−5	0	0	50	−30	50	do	Fixture.
	39	110	0	0	0	10	−35	25	do	Optimum.
	40	110	−10	0	5	40	−35	45	do	Fixture.
	41	110	−20	0	0	10	−40	40	do	Optimum.
	42	−20	0	0	----	−20	−20	25	do	Fixture.
	43	−15	−5	5	----	−30	−30	45	do	Do.
	44	−12.5	5	0	----	−25	−25	30	do	Do.
C	45	−12.5	2.5	10	----	−30	−30	20	do	Optimum.
	46	−12.5	1.5	5	----	−30	−30	15	dd	Fixture.
	47	−12.5	−2.5	5	----	−35	−35	15	do	Do.
	48	−10	−5	5	----	−45	−45	45	do	Do.

[1] Estimated.

tests, values of C_l' and C_n' were determined at angles of attack of 0°, 10°, 20°, 30°, and 40°, except at the most important positions where a more complete series of angles of attack was investigated.

The maximum aileron-deflection angles used in this part of the investigation were determined by one of two limiting conditions: (1) The aileron came in contact with the wing or the supporting brackets, (2) the value of C_l' reached a maximum positive or negative value (optimum). Table II lists the maximum deflection for each position and the limiting factor for each. For all cases that appeared to warrant it, tests were also made with about half the maximum deflection and, for the most important positions, tests were made at several intermediate aileron angles.

(4) **Lateral-stability tests.**—With the ailerons at some of the positions shown to be the more promising by the preceding tests (positions 1, 6, 26, and 35), the model was subjected to forced-rotation tests with 0° and 20° of yaw, in which the rolling moments due to rolling were measured. The rate of rotation employed about the wind axis (p') was such that $p'b/2V=0.05$, which corresponds to the maximum rolling velocity likely to be encountered in controlled flight in very gusty air. The rolling moments are given in terms of the coefficient $C_\lambda=\frac{\lambda}{qbS}$, where λ is the rolling moment measured while the wing is rolling.

Tests were also made in which the wing was allowed to rotate freely and the initial angles for instability were measured, both with the wing unyawed and yawed 20°.

Flight tests.—In order to obtain information on the hinge moment and lag characteristics of this type of lateral control, flight tests were made at the aileron position farthest ahead of the wing and at what appeared to be the best position in the region over the nose. The results obtained at the former position showed hinge moments to be so heavy that the control was completely useless. At the rear position the results were more satisfactory and are discussed later in more detail.

Tabular data.—Tables III to XXVI give the complete test data obtained with the ailerons in the more promising positions (nos. 1, 3, 6, 12, 26, 35, and 37). Criterions of speed range, climb, rolling control, yawing moments, and lateral stability (see reference 1) with the ailerons in these positions are presented in table XXVII. The effect on the criterions of permitting the symmetrical ailerons in positions 1 and 37 to float is also shown in this table.

DISCUSSION

The nature and degree of the change in the aerodynamic characteristics of a wing owing to the addition of ailerons mounted externally to it are dependent upon (1) the chord, span, and profile of the aileron, (2) the location of the aileron relative to the main wing, and (3) the manner in which the aileron is employed. In the present report the first classification of variables is taken into account by confining the principal discussion to one size and span of aileron and neglecting the effect of the small difference in aileron chords noted under Apparatus. This procedure appears permissible at the positions in which the N. A. C. A. 22 ailerons were tested but it probably would not be so in region B. The differences in characteristics obtained by use of symmetrical or cambered airfoils are noted, but not enough tests were made of both ailerons at the same position to warrant any general conclusions relative to the effect of aileron profile. The second variable is analyzed in some detail in a series of contour charts showing the effect of aileron-axis location upon the principal aerodynamic characteristics of the wing system. The third variable is taken into consideration by employing the ailerons in what appears to be the most efficient manner for the particular region in which they are mounted. Thus, in locations where the ailerons may be used to advantage as a flap, this feature has been investigated and the optimum deflections for lift and drag determined. Likewise, near the leading edge the possibility exists of improving the lift of the main wing by using the ailerons together as a slat. In other locations the most desirable arrangement is to mount the ailerons in such a way that they are deflected only for control, the neutral setting remaining constant for all flight conditions. The contour charts therefore show planes of discontinuity where the method of aileron operation changes. In the charts where the contours are broken near the leading edge, the test data were considered insufficient to complete the curves.

GENERAL PERFORMANCE

(AILERONS NEUTRAL)

Wing area for desired landing speed.—The value of $C_{L_{max}}$ may be used as a criterion of the wing area required for a desired landing speed or, conversely, for the landing speed obtainable with a given wing area. Figure 4 shows the effect of the axis location of the external aileron upon this parameter. Of the aileron locations tested in region A, where the aileron was not deflected except for lateral control, the best position was 27 percent of the main wing chord ahead of the leading edge and 13 percent above the chord line. This position corresponded very closely to that reported in references 2 and 3 as being the optimum location for a fixed auxiliary airfoil of the size and section used. Moving the ailerons closer to the leading edge of the main wing progressively reduced the obtainable value of $C_{L_{max}}$. If, however, the aileron axis were not moved back farther than about 15 percent of the main wing chord behind the leading edge or closer than about 10 percent from the upper surface, $C_{L_{max}}$ was not reduced below that obtainable with the plain wing (1.250).

When both the ailerons were allowed to float and to act as an automatic slat in region C, a value of $C_{L_{max}} = 1.734$ was obtained which is only slightly larger than that obtained at the best position as a fixed surface in region A (1.695). In position 35, region B, where the aileron could be used as a flap, a value of $C_{L_{max}}$ of 1.810 was obtained with both of the ailerons deflected 45° down. This value is about 4½ percent higher than that obtained at the best of the forward positions and about 45 percent higher than that for the main wing alone, the coefficients being based on the total area.

High speed.—The value of $C_{D_{min}}$ of a wing may be used as a criterion of its suitability for high-speed use when comparing similar airplanes equipped with wings of equal area. The variation of the values of $C_{D_{min}}$ with aileron-axis location is shown in figure 5. The relatively large variations in $C_{D_{min}}$ between the best and the worst positions, and the relation of the various ences 5 and 6, compensated for the differences in the characteristics of the variable-density wind tunnel and the 7- by 10-foot atmospheric wind tunnel, the value of $C_{D_{min}}$ for the aileron is estimated to be 0.0135. From these values it follows that with no interference the value of $C_{D_{min}}$ of the combination would be about 0.0152.

The relatively high values of $C_{D_{min}}$ found for aileron positions in region A may be attributed to the high air speeds in this region. The small decrease in value at the farthest forward position (optimum) was no doubt due to the increased supporting-fixture drag almost counterbalancing the effect of the decreased air speed at this point. The very high value found at the aileron positions closest to the wing and 30 to 40 percent of the chord from the leading edge is attributable to high speeds plus a strong unfavorable interference effect between the wing and aileron when they are less than 5 percent of the main wing chord apart.

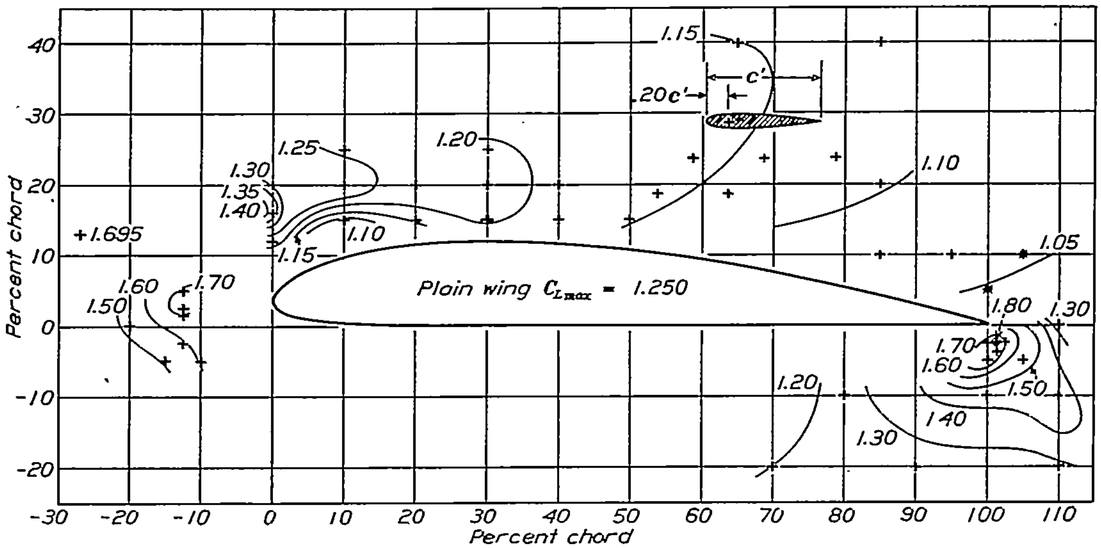


FIGURE 4.—Effect of location of external ailerons on $C_{L_{max}}$.

values to that for the wing alone may be best analyzed by a consideration of the three principal controlling factors: (1) The minimum values of the drag coefficients for the wing and ailerons separately; (2) any mutual interference effects between the wing and the ailerons whereby the presence of one airfoil changes the apparent value of C_D of the other one by affecting the velocity, turbulence, or curvature of the air stream passing over it; and (3) the supporting-fixture drag—a factor that is included in all values of $C_{D_{min}}$ given in this report.

The relative importance of each of these factors at any particular location may be estimated by determining the minimum drag coefficients of the wing and aileron separately, and the least obtainable value of $C_{D_{min}}$ if the effect of the last two factors be considered negligible. Tests showed the main wing to have a value of $C_{D_{min}}$ of 0.0155. From data given in refer-

This high-drag area may be expected to continue forward to the leading edge for aileron positions closer to the upper surface than those tested.

In region C, in front of and below the nose, the aileron position having the lowest drag represents the nearest approach to the ideal conditions previously outlined, wherein all the factors tending to increase the drag are a minimum and the resulting drag is nearly the sum of the drag of the two airfoils taken separately.

In region B, a reduction in drag due to the ailerons operating in the wake of the main wing is noticeable.

Speed range.—The ratio $C_{L_{max}}/C_{D_{min}}$ is a convenient figure of merit for comparing the effectiveness of different wings in giving a large speed range. Figure 6 shows the effect of the aileron location upon this criterion. Inasmuch as the value of $C_{L_{max}}/C_{D_{min}}$ for the wing alone is approximately 80, it is apparent that

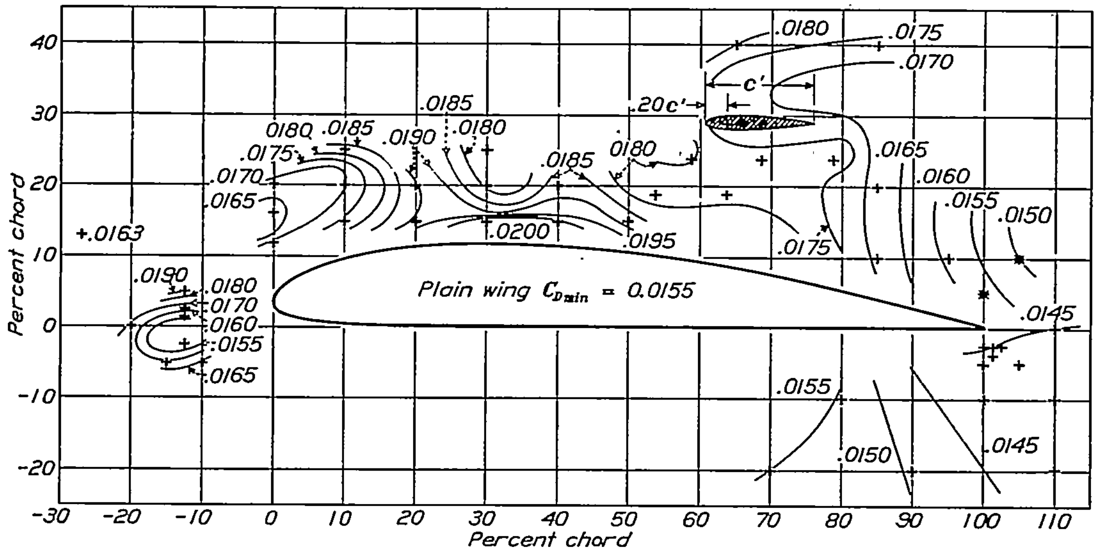


FIGURE 5.—Effect of location of external ailerons on $C_{D_{min}}$.

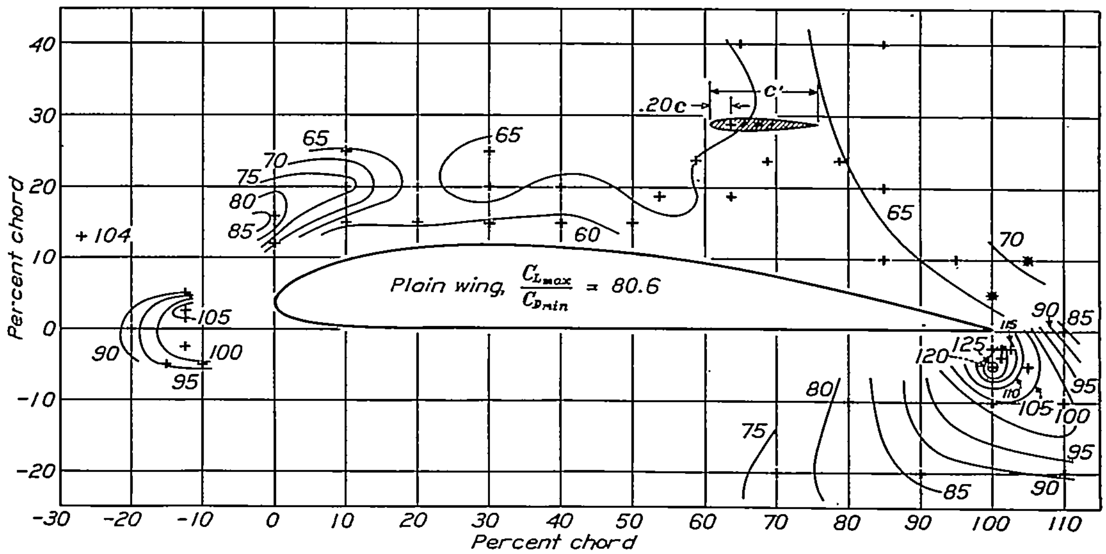


FIGURE 6.—Effect of location of external ailerons on the ratio $C_{L_{max}}/C_{D_{min}}$.

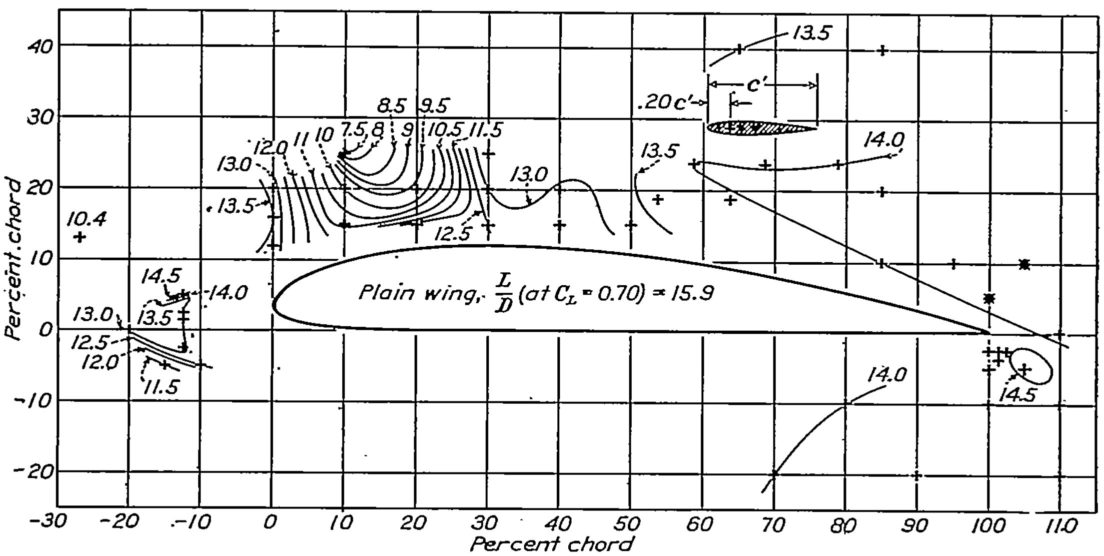


FIGURE 7.—Effect of location of external ailerons on the L/D ratio at C_L=0.70 (rate-of-climb criterion).

only the extreme forward positions of the aileron show improved performance over the plain wing if the aileron is fixed when neutral. The best floating position just ahead of and below the nose, region C, gives approximately the same value (109.1) as the best fixed position in region A (104.0), but the best flap position under the trailing edge, region B, gives a substantially higher value (124.0).

Rate of climb.—In order to establish a suitable criterion for the effect of the wing and lateral control system on the rate of climb of an airplane, the performance curves of a number of types and sizes of airplanes were calculated, and the relation of the maximum rate of climb to the lift and drag curves was studied. This investigation showed that the L/D at $C_L=0.70$ gave a consistently reliable figure of merit for this purpose. Figure 7 shows the effect of the location of the axis of external ailerons on this criterion. The values shown were not in every case the maximum obtainable but the variation of the criterion with aileron angle was small in the range of angles tested, so that no appreciable difference in the contours would exist if all points had been plotted for the exact maximum values of the criterion.

In region C the ailerons were free to float between stops. In positions 42, 44, 45, and 46 the ailerons were against the upper stop for $C_L=0.70$. In positions 43 and 47 the ailerons rested against either stop at the angle of attack for $C_L=0.70$, depending upon whether the angle of attack had been approached from above or below. Slightly different values of the criterion were obtained under the two conditions, the average of the two readings being plotted. In position 48 the ailerons were against the lower, or high speed, stop at the critical value of C_L. It is probable that the ailerons were not even approximately in their best attitude for climb in any of the positions in this group, except perhaps the highest one, position 44.

In a consideration of the aileron positions in region A, a section of very low values of the climb criterion is seen to occur about 15 percent of the chord from the leading edge. Farther back the criterion rises to a value almost equal to the maximum measured in these tests. A value of the criterion equal to those occurring near the trailing edge probably might be found between 5 and 10 percent ahead of the leading edge and from 5 to 15 percent of the chord above the chord line.

The flap positions in region B also gave values as high as any others found with the external ailerons, but all the values found with the ailerons were definitely lower than that for the main wing alone.

LATERAL CONTROL

(AILERONS FULLY DEFLECTED)

The rolling-moment coefficient produced by the ailerons about the wind, or tunnel, axis is used as the primary basis for comparison of the aileron locations discussed in this report. The rolling-moment coefficient about the wind axes C_l' is used in preference to the coefficient about the body axes, as given in some previous reports in this series, because of a better qualitative agreement of the results with flight tests reported in reference 7.

As previously stated, the setting of the neutral aileron at each location in region A corresponded to that giving the best general performance. In region C the neutral setting was the attitude that the neutral aileron would take if the ailerons were allowed to float between stops, as outlined in the discussion of general performance. Thus, for up-only deflection, the right aileron was deflected with its trailing edge up and the left aileron was against the lower stop; and for down-only deflection, the left aileron was deflected with its trailing edge down and the right aileron was against the upper stop. In region B, where the aileron acted as a flap, the neutral aileron setting was taken arbitrarily as the angle giving the maximum value of L/D at $C_L=0.70$ (table II). This value of the neutral angle was the same as that for minimum drag, in almost all cases. In the few exceptions, the critical angle of deflection was 10° to 15° greater. The data plotted on this basis are intended to give only a general picture of the moments obtainable in the various locations, the more promising locations being dealt with later in greater detail.

Maximum deflections of the ailerons were governed, in all cases, by interference with the wing, interference between the aileron and its supporting brackets, or by a maximum positive or negative value of C_l' being recorded at some smaller deflection than the limit set by interference conditions. It is therefore apparent that the extreme deflections up or down were not uniform for all positions, but discrepancies in the contours arising from this source are considered unimportant.

The contour charts are plotted for deflection of the right aileron up or the left aileron down. If it is desired to estimate the effect of deflecting the ailerons differentially at any particular location, the algebraic sum of the moments due to the right and left ailerons deflected separately must be used.

Figures 8, 9, and 10 show the variation of C_l' with aileron-axis location for up-only deflection of the right aileron at $\alpha=0°$, 10°, and 20°, respectively. Figures 11, 12, and 13 give the corresponding variation in C_n'. The values of α used correspond, respectively, to high-speed flight, the maximum angle at which ordinary ailerons are usually considered to be satisfactory, and stalled flight. Considering, first, all positions lying in regions A and C, two tendencies are noticeable. First, the region for most effective action of the ailerons as a spoiler moved gradually forward with increasing angle of attack from about 60 percent of the chord at 0° to about 30 percent at 20°. Associated with this movement was a progressive increase in the rolling-moment coefficient obtainable. At the optimum

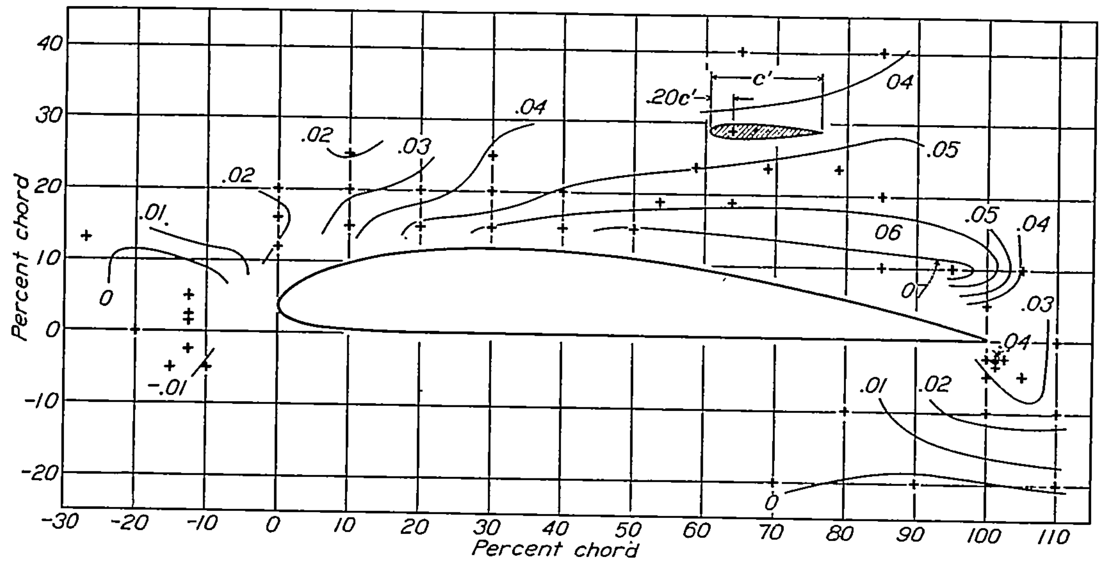


FIGURE 8.—Effect of location of external ailerons on C_{l}'. Right aileron deflected up-only. $\alpha=0°$.

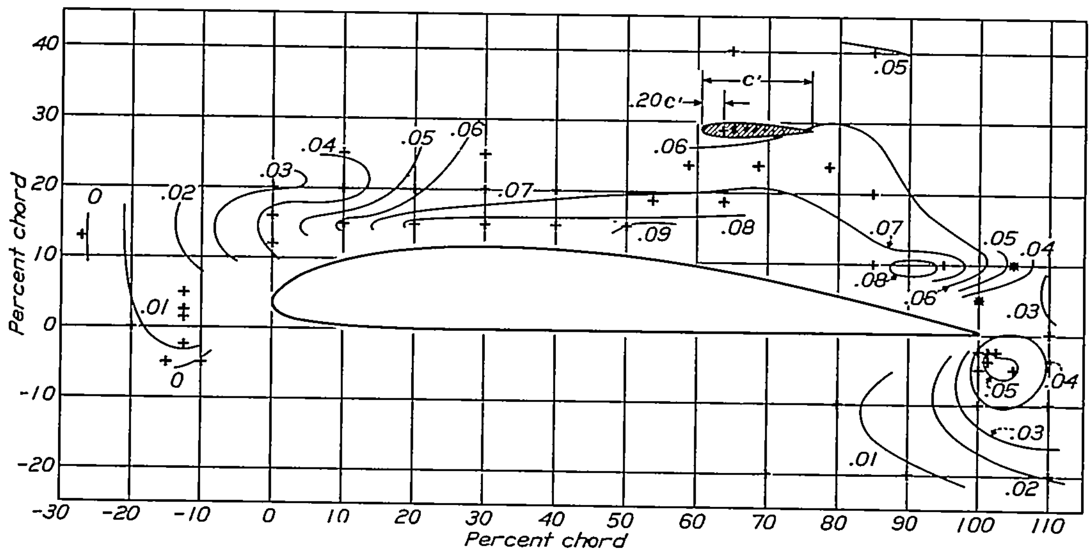


FIGURE 9.—Effect of location of external ailerons on C_{l}'. Right aileron deflected up-only. $\alpha=10°$.

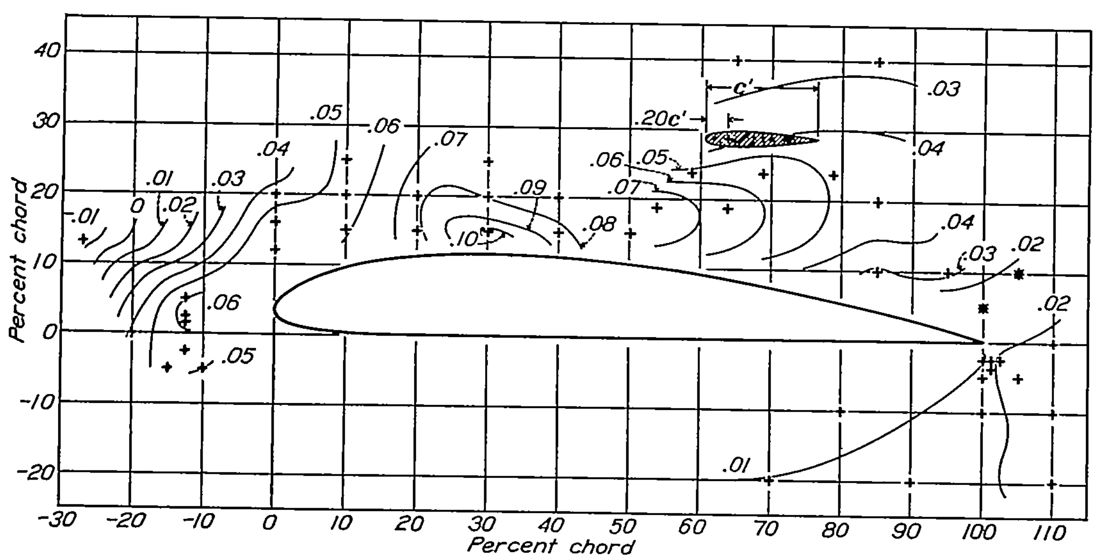


FIGURE 10.—Effect of location of external ailerons on C_{l}'. Right aileron deflected up-only. $\alpha=20°$.

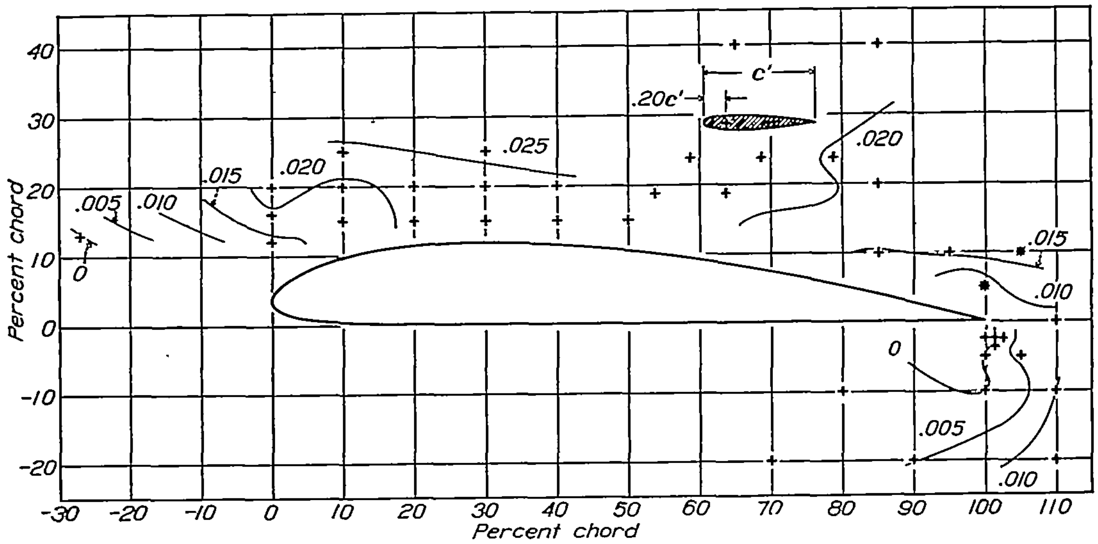


FIGURE 11.—Effect of location of external ailerons on C_n'. Right aileron deflected up-only. $\alpha=0°$.

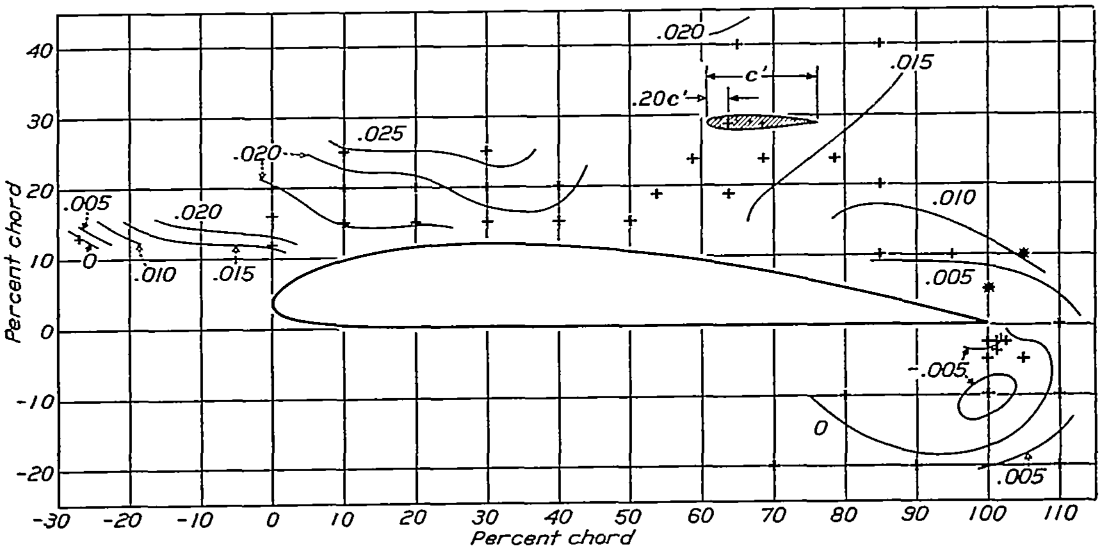


FIGURE 12.—Effect of location of external ailerons on C_n'. Right aileron deflected up-only. $\alpha=10°$.

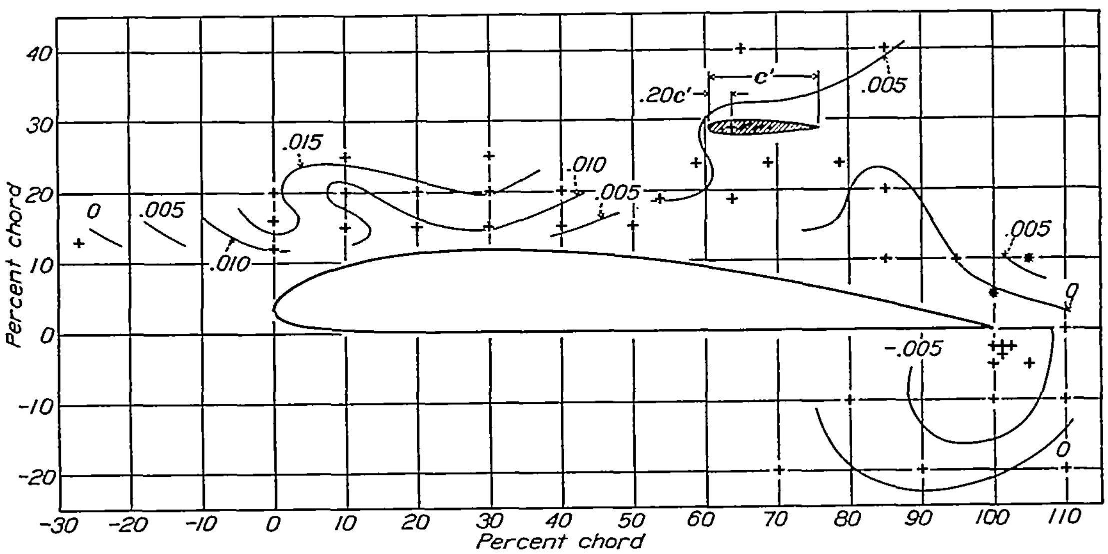


FIGURE 13.—Effect of location of external ailerons on C_n'. Right aileron deflected up-only. $\alpha=20°$.

position for rolling moment at stalling attitudes, the increase in C_l' was from 0.0601 at $\alpha=0°$ to 0.1007 at $\alpha=20°$.

The yawing moments accompanying the above-mentioned rolling moments were positive at all angles of attack and were of magnitudes equal to or greater than the yawing moment produced by a conventional rudder. At the position for optimum C_l' at $\alpha=20°$ (position 12), the variation in C_n' with angle of attack was opposite to that shown by C_l'; that is, C_n' decreased with increasing angle of attack.

The second item of interest is the constancy of the rolling-moment coefficient obtained at the positions near the trailing edge where the "up-aileron" is the dominating source of control. Position 26 is approximately the best in this region and corresponds closely to the location of Zap ailerons (reference 8). The rolling-moment coefficients here were found to be about equal, at normal angles of attack, to those obtainable farther forward where the aileron action is more that of a spoiler; but, once the wing was stalled, the effectiveness of the ailerons was found to be seriously reduced.

Yawing moments at position 26 showed the same characteristics—positive and decreasing with increasing α—as at the positions farther forward, with the exception that the moment at all angles of attack was definitely smaller. The rate of decrease in yawing moment with increasing angle of attack was higher at this position than farther forward, which resulted in almost complete disappearance of any yawing moment at $\alpha=20°$.

When the aileron movement was down-only (figs. 14, 15, and 16) the rolling moments were somewhat different. The optimum location for the aileron when acting as a spoiler was farther forward and, obviously, higher up. A similar, though greater, increase in effectiveness with angle of attack was noted in this region, the maximum value being slightly greater than that obtained at the best position for up-only deflection. Near the trailing edge, on the other hand, down-only deflections gave very low but always positive rolling moments. This condition may be attributed to interference effects causing a loss in lift on the trailing edge of the main wing, which almost counterbalanced the increased lift on the aileron.

Yawing moments produced by the ailerons when deflected down-only (figs. 17, 18, and 19) in the best region near the leading edge showed similar characteristics to those obtained by the aileron when deflected up-only. This result is to be expected, since in each case the action of the aileron was to spoil the air flow over the wing behind it. At position 26 the yawing moments were very small and negative (adverse) at all angles of attack. Comparing up deflection with down deflection at the same angles of attack, on the basis of maximum rolling and yawing moments, up-only deflection seems to be preferable in both the forward "spoiler" region and near the trailing edge. Flight tests with the ailerons mounted in position 6 disclosed that this direction of deflection has the added advantage of counteracting the lag, characteristic of a spoiler (reference 7), by creating a down load on the aileron as soon as it is deflected and before the flow over the main wing has had a chance to assume its new pattern. A limited differential movement is aerodynamically preferable to a motion in one direction only near the trailing edge but is distinctly not advisable in the best positions farther forward.

The small negative rolling moments, which occurred at $\alpha=0°$ at the floating leading-edge positions with either up or down deflection (figs. 8 and 14), may be explained by the fact that the lift curves were almost coincident for all aileron settings at this angle of attack and that a deflection in either direction caused a shift in the lift curve opposite to that occurring at higher angles of attack. Thus, external ailerons in region C would be apparently unsatisfactory as practical lateral control devices if used alone.

The contours of rolling and yawing moments produced by external ailerons below the trailing edge follow, with a few exceptions, the characteristics of ordinary ailerons. Up-only deflection produced slightly lower rolling moments than down-only at normal angles of attack, apparently owing to the greater shielding by the wing when the trailing edge of the aileron was deflected upward. Down-only deflection produced small negative rolling moments beyond the stall, whereas up-only deflection produced small positive moments. Yawing moments were consistently negative and large when the aileron was deflected down-only. With up-only deflection the yawing moments were either positive or negative, depending on the angle of attack and the proximity of the aileron to the main wing. At $\alpha=0°$ a limited region of small negative yawing moments existed close to the trailing edge of the main wing. At higher angles of attack this negative region expanded considerably and negative moments reached a maximum value of -0.0095 at position 30 and $\alpha=20°$.

It is of interest to note the relatively sudden drop in yawing moment for both upward and downward deflection for aileron positions occurring just to the rear of the trailing edge of the main wing. This characteristic is due to the fact that the angle of deflection for maximum rolling moment at position 37 was less than at position 35. Rolling moments obtained at the two positions showed position 35 to be preferable for use with down-only deflection, except at $\alpha=20°$; and position 37 better with up-only deflection, except at $\alpha=0°$. Since the rolling moment obtainable is not the deciding factor the choice of one of the two positions for an optimum, using both up and down deflection, lies in evaluating the relative desirability

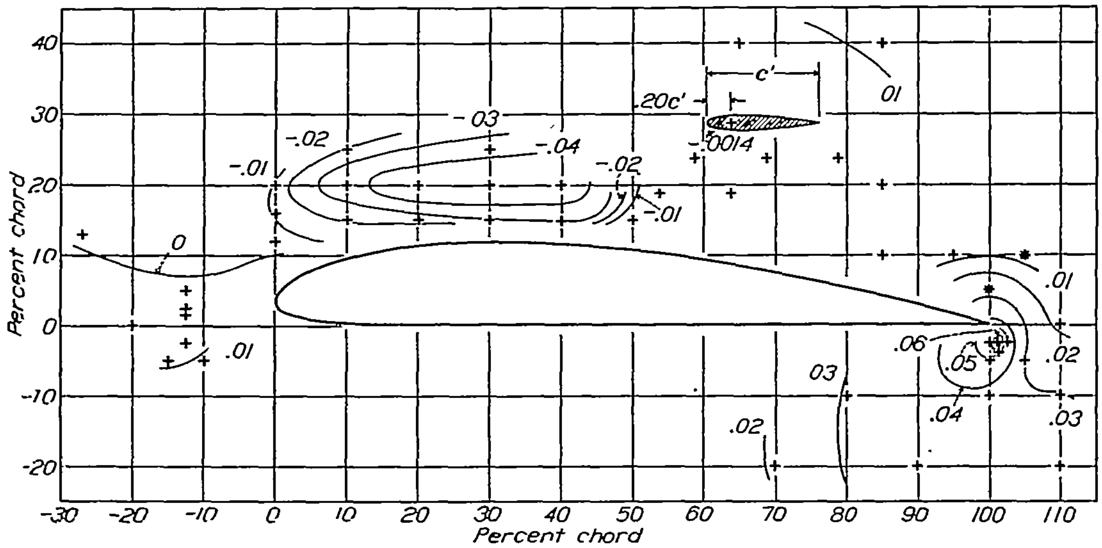


FIGURE 14.—Effect of location of external ailerons on C_l'. Left aileron deflected down-only. $\alpha=0°$.

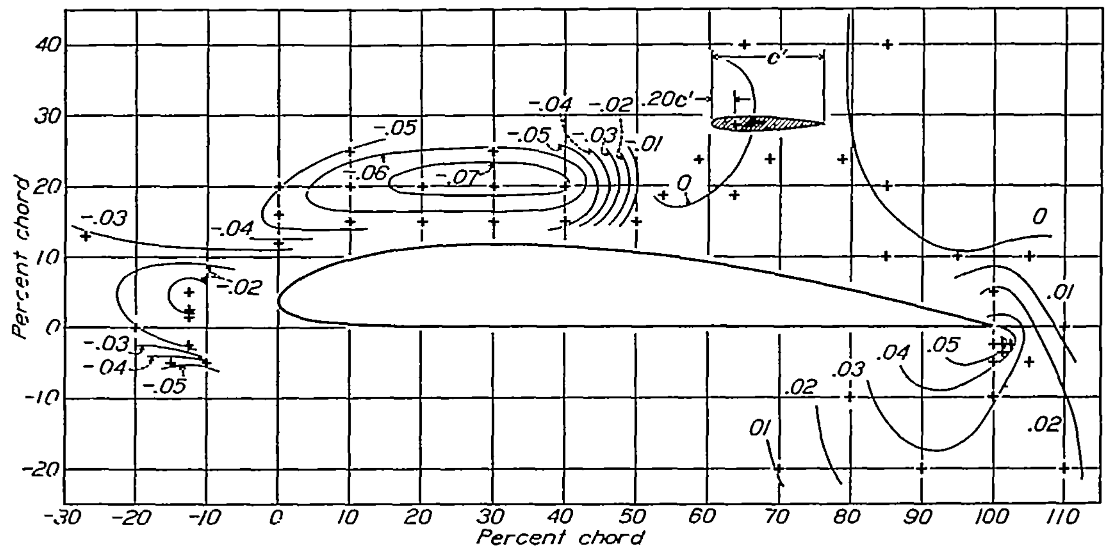


FIGURE 15.—Effect of location of external ailerons on C_l'. Left aileron deflected down-only. $\alpha=10°$.

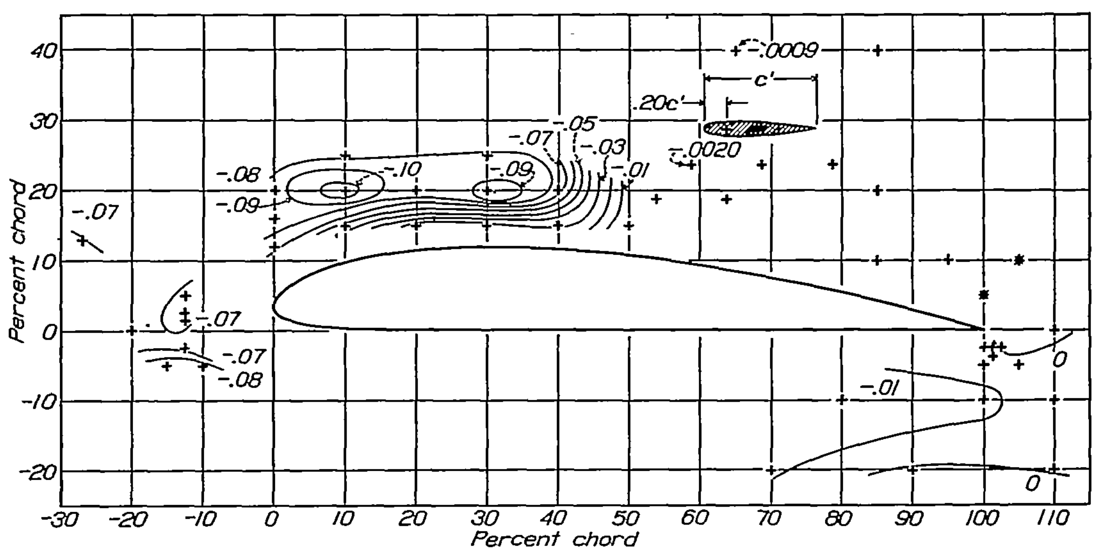


FIGURE 16.—Effect of location of external ailerons on C_l'. Left aileron deflected down-only. $\alpha=20°$.

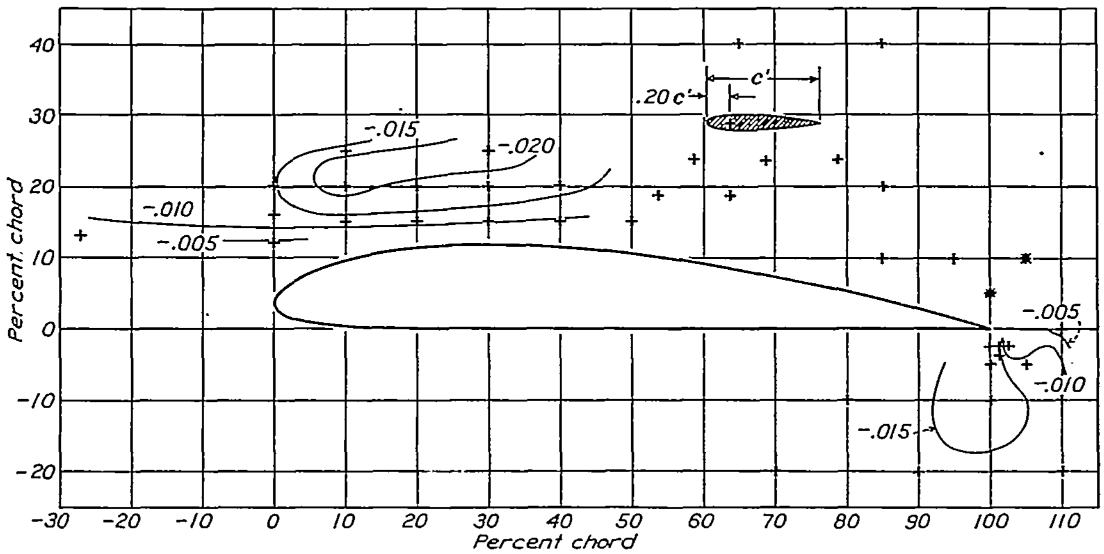


FIGURE 17.—Effect of location of external ailerons on C_n'. Left aileron deflected down-only. $\alpha=0°$.

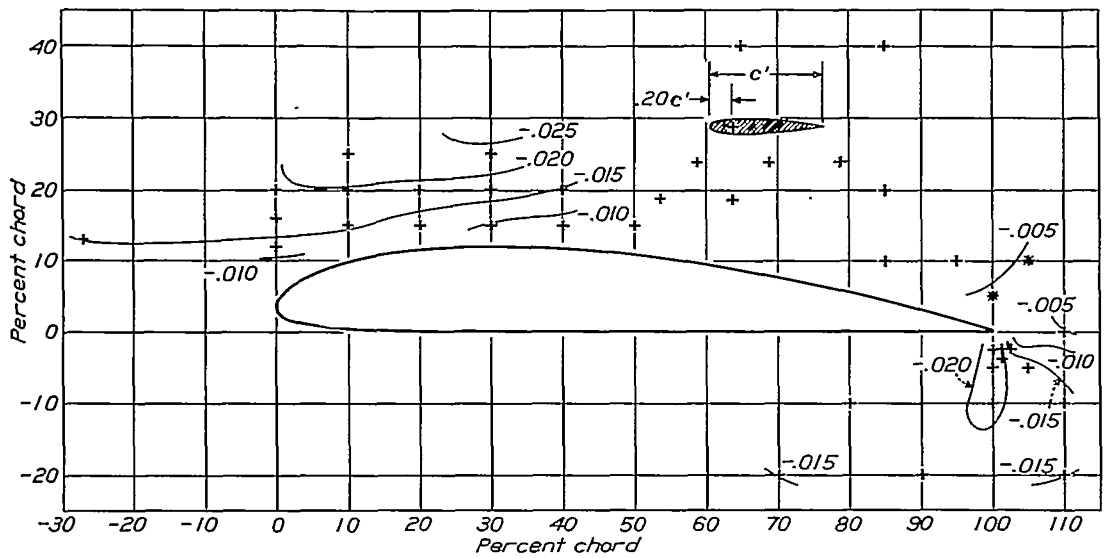


FIGURE 18.—Effect of location of external ailerons on C_n'. Left aileron deflected down-only. $\alpha=10°$.

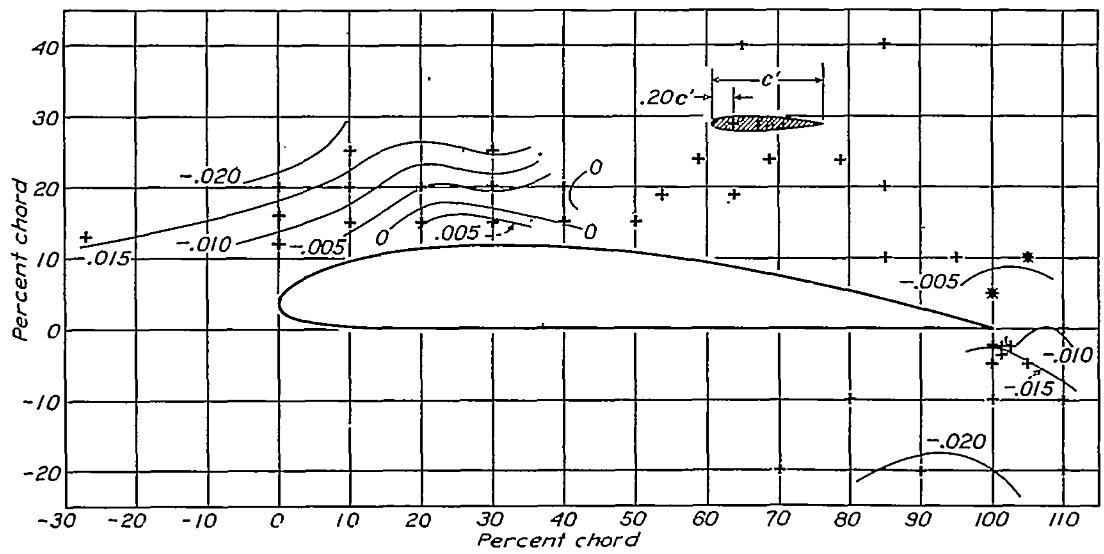


FIGURE 19.—Effect of location of external ailerons on C_n'. Left aileron deflected down-only. $\alpha=20°$.

of maximum lift, speed range (see figs. 4 and 6), and adverse yawing moments.

CRITERION TABLE

General performance or control.—The principal characteristics of the model with the external ailerons mounted in seven positions of especial interest (1, 3, 6, 12, 26, 35, and 37) are presented in table XXVII with the corresponding data for the plain wing with no ailerons and with ordinary ailerons of average size. The external aileron positions listed were chosen as being the most favorable for performance and/or control as pointed out in the preceding discussion.

Three possible arrangements are given for position 1: Cambered ailerons and symmetrical ailerons each fixed at its optimum setting, and symmetrical ailerons arranged to float. The table shows that the cambered ailerons gave the higher maximum lift coefficient but the symmetrical ones gave a lower minimum drag coefficient. The rate-of-climb criterion is low for all three cases as compared with that obtained with the plain wing, that with the fixed symmetrical ailerons being definitely the lowest.

With respect to control, the wing with the cambered N. A. C. A. 22 ailerons is best at low angles of attack but the effectiveness of even this arrangement is very low as compared with that obtainable with ordinary ailerons. The value of the rolling criterion ($RC'=C_l'/C_L$) shown is below what may be considered the extreme lower limit of usable control, being about one-third of the value that has been taken as satisfactory in this series of tests ($RC'=0.075$). At higher angles of attack the value of RC' with all three arrangements increases to what is probably a usable value (0.040).

Yawing moments obtained by use of external ailerons in this location were always positive and fairly large except when the airfoil was allowed to float. The secondary rolling moments resulting from the yawing motion and attitude induced by these moments would improve the rolling control obtainable, but it is not likely that the entire effect would be satisfactory. In addition, full-scale tests (not yet published) have shown that this lateral control system suffered from an appreciable time lag between the instant of control-stick movement and the beginning of a rolling motion.

Three positions (3, 6, and 12) are of interest as possible locations for nonfloating external ailerons mounted above the forward part of the main wing. Position 12 is the aileron location at which the greatest rolling control was obtainable without regard to the effect of the ailerons on the performance of the main wing. Position 6 was tested in flight because it showed better general performance characteristics than position 12 and only slightly different control effectiveness. Position 3 shows the available rolling control at an aileron location that detracts the least from the performance characteristics of the plain wing. Each of these positions is discussed in detail in the following paragraphs.

Position 12 is considered to be representative of the best location for external ailerons when no account is taken of the effect of the ailerons on the general performance of the main wing. Values of RC' obtained at this position were equal to or better than those for plain ailerons at $\alpha=0°$ and $10°$ and were more than twice as great at $\alpha=20°$. At $\alpha=30°$ the control failed completely, but the importance of results at this angle of attack is slight. Yawing moments were large and positive at all angles of attack up through 20°. Small negative yawing moments appeared only at low deflections at $\alpha=20°$ and at about half deflection at $\alpha=30°$. Lag in the control action following displacement of the ailerons should not be appreciable with up-only movement at this axis location because the immediately effective down load on the aileron itself tends to counteract the delay (characteristic of plain spoilers) between the time of control movement and the reestablishment of steady flow conditions.

The disadvantages of mounting external ailerons at position 12 are mainly due to their effect on the general performance of the wing system. The value of $C_{L_{max}}$ was only decreased about 3½ percent, but that of $C_{D_{min}}$ was increased 30 percent, resulting in a decrease in the ratio $C_{L_{max}}/C_{D_{min}}$ of 35 percent. The climb criterion was likewise decreased from 15.9 for the plain wing to 12.5 for the wing with external ailerons.

The general performance characteristics of the wing with the external ailerons in position 6 were superior, except for climb, to those obtained when the ailerons were mounted in position 12. Flight tests were made on a Fairchild 22 airplane equipped with external ailerons in position 6, having spans equal to half the wing semispan and chords 15.2 percent of the main wing chord. These tests showed a serious lag in control response when the aileron was deflected downward, and heavy hinge moments with either direction of deflection. Use of up deflection eliminated the lag. The axis position was moved in steps from 20 percent of the chord of the aileron to 25 percent of the chord in an attempt to decrease the hinge moment but this amount of movement was found to be insufficient to reduce the moment to a satisfactory magnitude. The axis was not moved farther to the rear because of indications of overbalance.

The values of RC' and yawing-moment coefficients given in table XXVII for position 6 are from the results of the wind-tunnel tests using up-only deflection. Downward deflection gave somewhat greater control effectiveness, but the lag characteristics associated with this type of movement render it entirely unsuitable for use.

Table XXVII shows the performance values of a wing with external ailerons mounted in position 3 to be practically equal to those for a plain wing, except for climb. The values of RC' show the relatively unusual characteristic of being almost constant relative to angle of attack up to $\alpha=20°$. A loss in control occurs beyond this angle of attack but the decrease is much smaller than that experienced by the wing equipped with plain ailerons or any of the external ailerons thus far discussed except in the farthest forward location, position 1. The magnitude of the rolling criterion shows the control to be usable but, if the secondary rolling moments due to the strong positive yawing moments are taken into consideration, somewhat greater rolling action may be expected. The direction of deflection (up) for best control at this aileron location is such that little or no lag might be expected.

It is of importance to note that at positions 1, 3, 6, and 12 the best control effectiveness is obtained by a relatively large deflection of only one aileron. Mechanical linkages to obtain this type of motion with a smoothly acting control having light operating forces are extremely difficult to devise. The mechanical advantage is poorer than when both ailerons move simultaneously through smaller deflections, and the inertia effect when one aileron must be brought to rest and the other put in motion in reversing control is undesirable. These problems are greatly simplified by the conventional aileron linkages in which the ailerons move through the neutral position. This condition could be obtained in some measure for the external ailerons by rigging them at a slightly nose-down angle when neutral (nose up for position 1) and giving them an extreme differential motion. Figures 20, 21, 22, and 23 show, however, that the minimum drag would be increased and the maximum lift slightly decreased by such an expedient. (See also reference 3.)

Position 26 corresponds closely to the position for the Zap aileron. The general performance of the wing with the external ailerons in this location was found to be distinctly inferior to the plain wing when either a symmetrical or a cambered airfoil was used. (See fig. 24 and table XXVII.) The cambered airfoil was mounted inverted for the purpose of investigating the possibility of reducing the minimum drag. Apparently the camber of the N. A. C. A. 22 airfoil was too great to accomplish this object because the symmetrical airfoil set at the same optimum angle resulted in a lower minimum drag. Even in this case no reduction in drag as compared to that of the plain wing was effected. Control effectiveness as measured by RC' was equal to or slightly better than that with plain ailerons up through $\alpha=20°$. Yawing moments for the wing with either type of ailerons were positive and large at low angles of attack but fell off as α increased and became slightly negative at and above $\alpha=20°$. This condition compares favorably with the characteristics of ordinary ailerons, which give negative yawing moments at all angles of attack.

In region B the ailerons may be used as flaps as well as ailerons. The characteristics of positions 35 and 37 (see figs. 25 and 26) overlap in a manner that prevents definite preference of one to the other. In a comparison of the various features of both positions simultaneously the following points may be noted: The location of the two positions differed by only 1¼ percent of the main wing chord. The angle of deflection of the ailerons for minimum drag was the same for both positions but the angle for maximum lift was considerably greater at the forward position 35 than at position 37. These conditions indicate that smaller control forces are required to lower the flap in position 37. Maximum lift and minimum drag for the two positions with the flap up were the same, taking into account the accuracy of determination of the results. In regard to $C_{L_{max}}$ with the flap down, position 35 was superior by about 6 percent, the value obtained (1.810) being the highest of any found in the course of this investigation. Speed range, as indicated by the criterion $C_{L_{max}}/C_{D_{min}}$, shows the forward position to be slightly preferable. The climb criterion is shown appreciably different for the two positions, but it is to be noted that the value given for position 37 is for a downward aileron deflection of 5°, whereas the angle for position 35 is the same as that for high speed ($\delta_A=-5°$). No real difference between the two aileron locations would be expected to exist, however, if the optimum setting of the flap for climb had been used in each case.

The two positions were practically equal with regard to rolling moments except at the relatively unimportant angle of attack of 30° where the position 37 was distinctly better. Yawing moments for the two positions had large adverse values at all angles of attack but at $\alpha=10°$ and $\alpha=20°$ they were in the order of 40 percent lower and at $\alpha=0°$ they were about 75 percent lower at position 37 than at 35. In fact, the yawing moments for position 37 are no greater than those for standard conventional ailerons with equal up-and-down deflection.

Position 37 probably represents the nearest approach to satisfactory control of any of the external aileron positions tested. At this point the control action is not greatly different from that of conventional ailerons. It should be noted, however, that the control linkage for obtaining the best possible results with the dual action of flap and aileron is likely to be relatively complicated. In addition, when the aileron is deflected from the high-lift position the large amount of up-only deflection is likely to result in an unstable control force unless special precautions are taken to avoid this tendency. These disadvantages might be overcome, however, if the maximum rolling control were not required. For example, a moderate amount of control with a reasonably high value of $C_{L_{max}}$ could be obtained

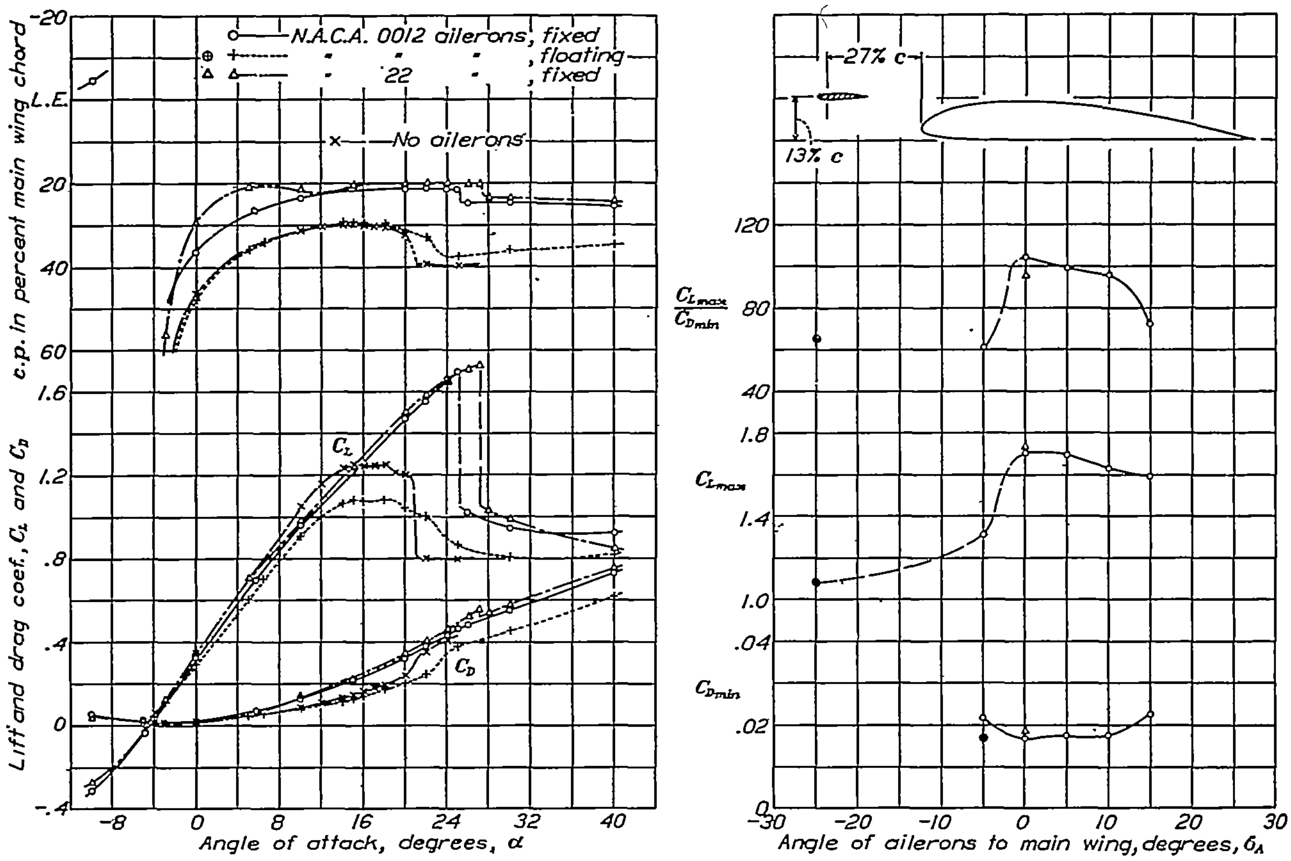


FIGURE 20.—Lift, drag, and center of pressure of Clark Y wing with symmetrical and cambered external ailerons in position 1.

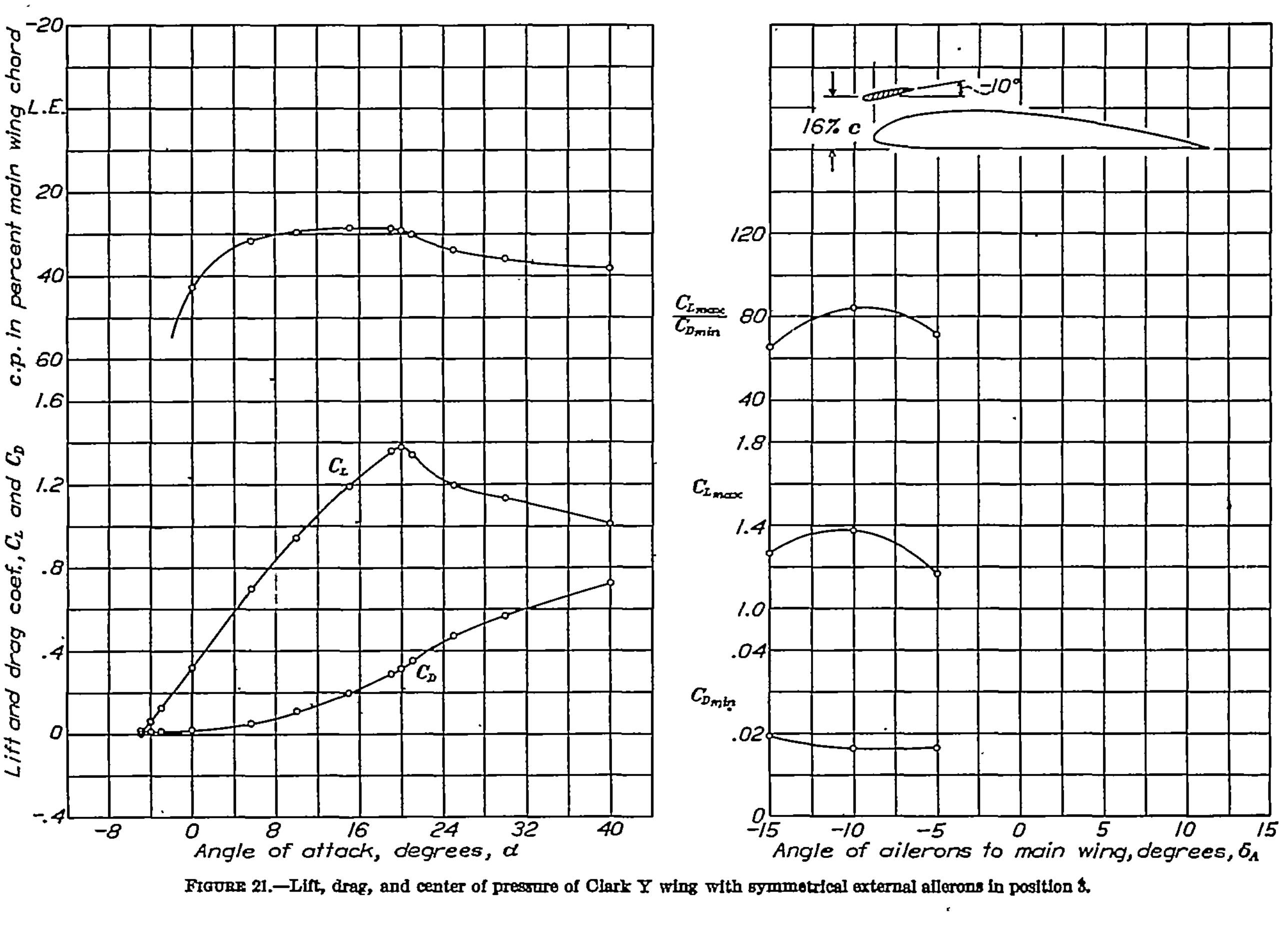


FIGURE 21.—Lift, drag, and center of pressure of Clark Y wing with symmetrical external ailerons in position 3.

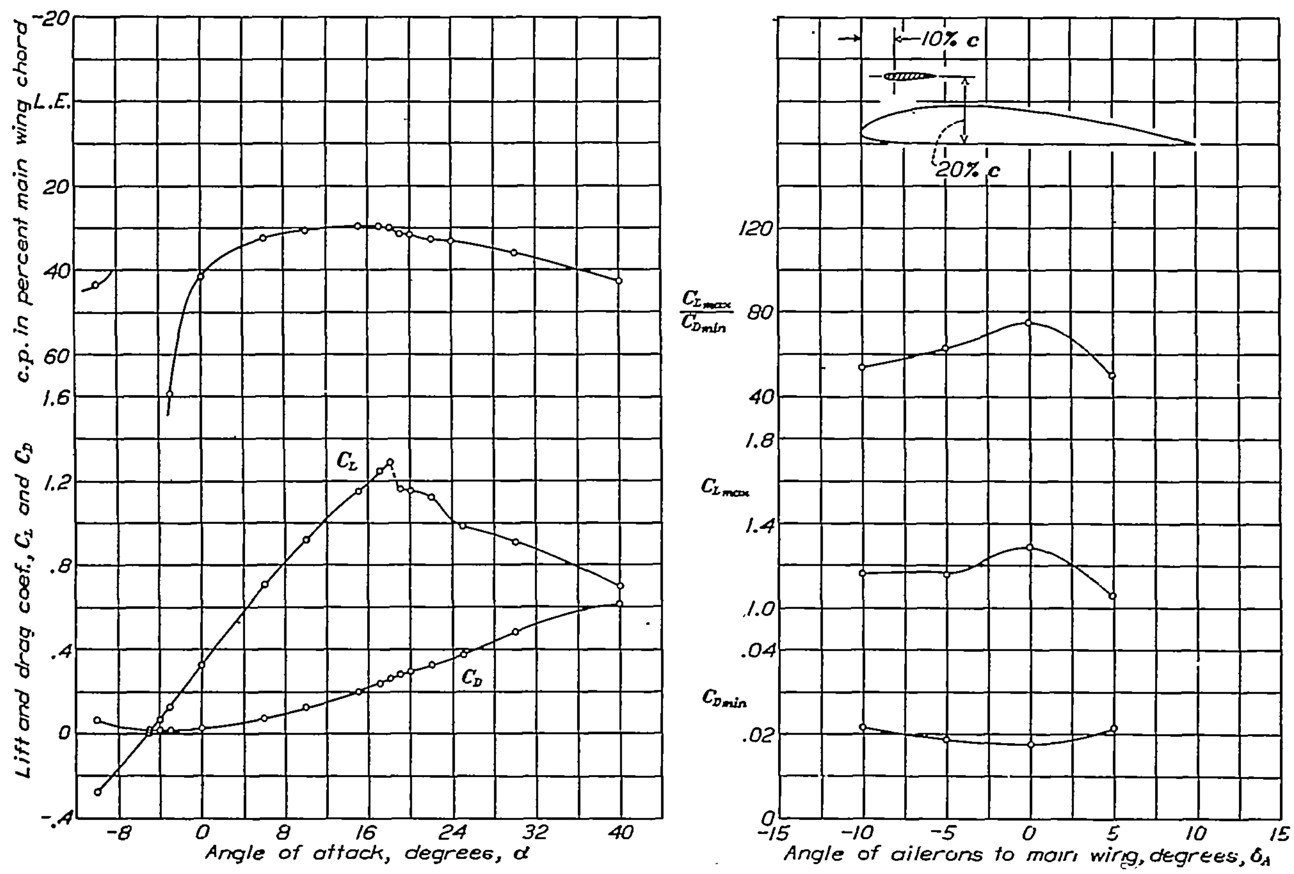


FIGURE 22.—Lift, drag, and center of pressure of Clark Y wing with symmetrical external ailerons in position 6.

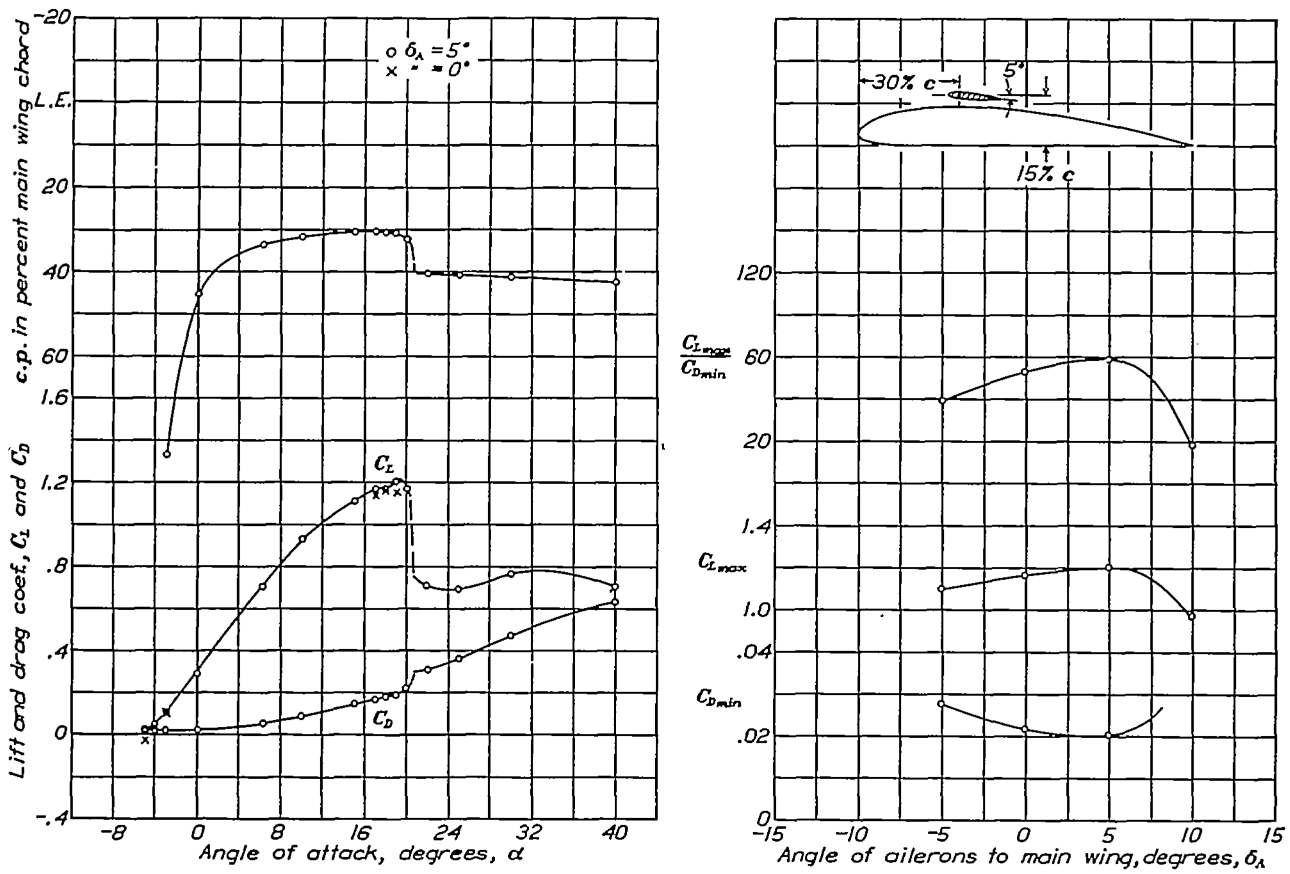


FIGURE 23.—Lift, drag, and center of pressure of Clark Y wing with symmetrical external ailerons in position 12.

71040—30——8

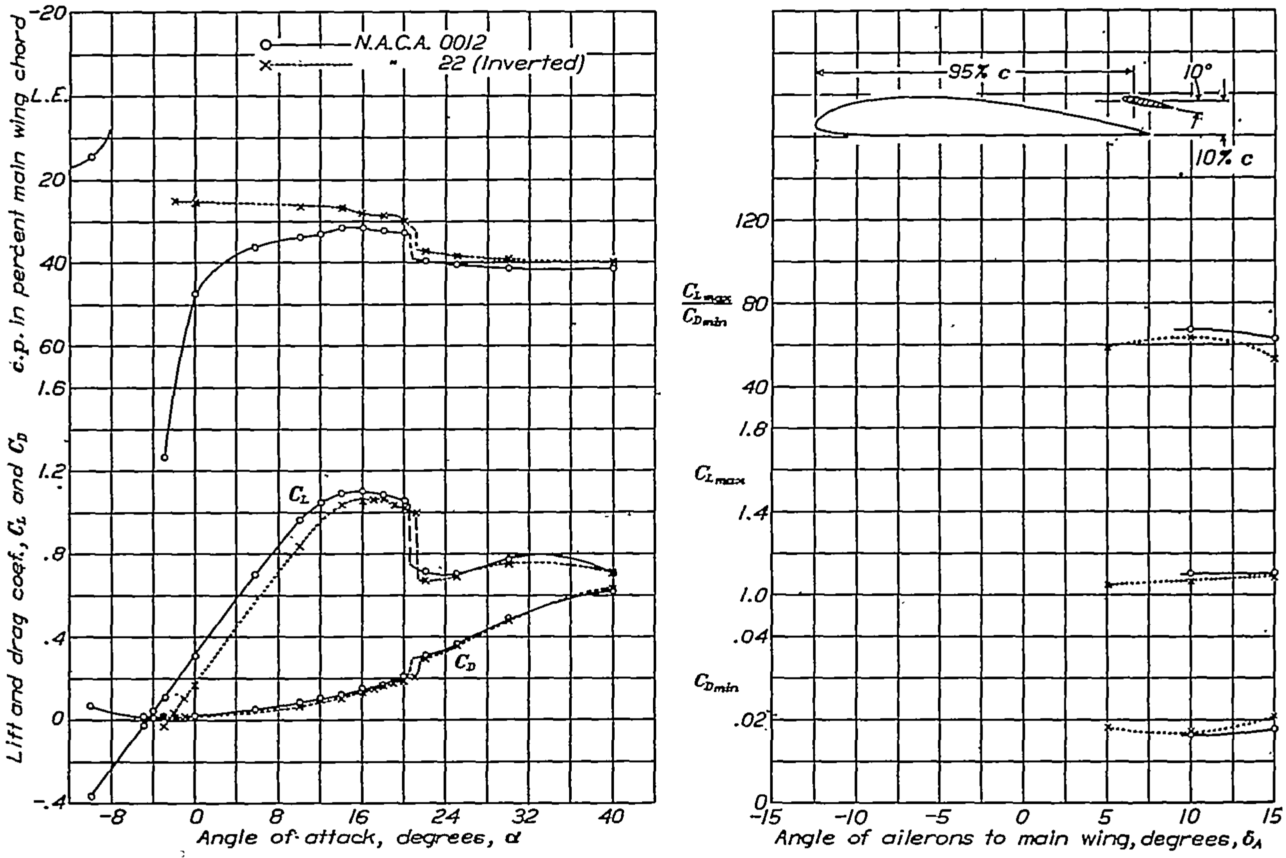


FIGURE 24.—Lift, drag, and center of pressure of Clark Y wing with symmetrical and cambered external ailerons in position 26.

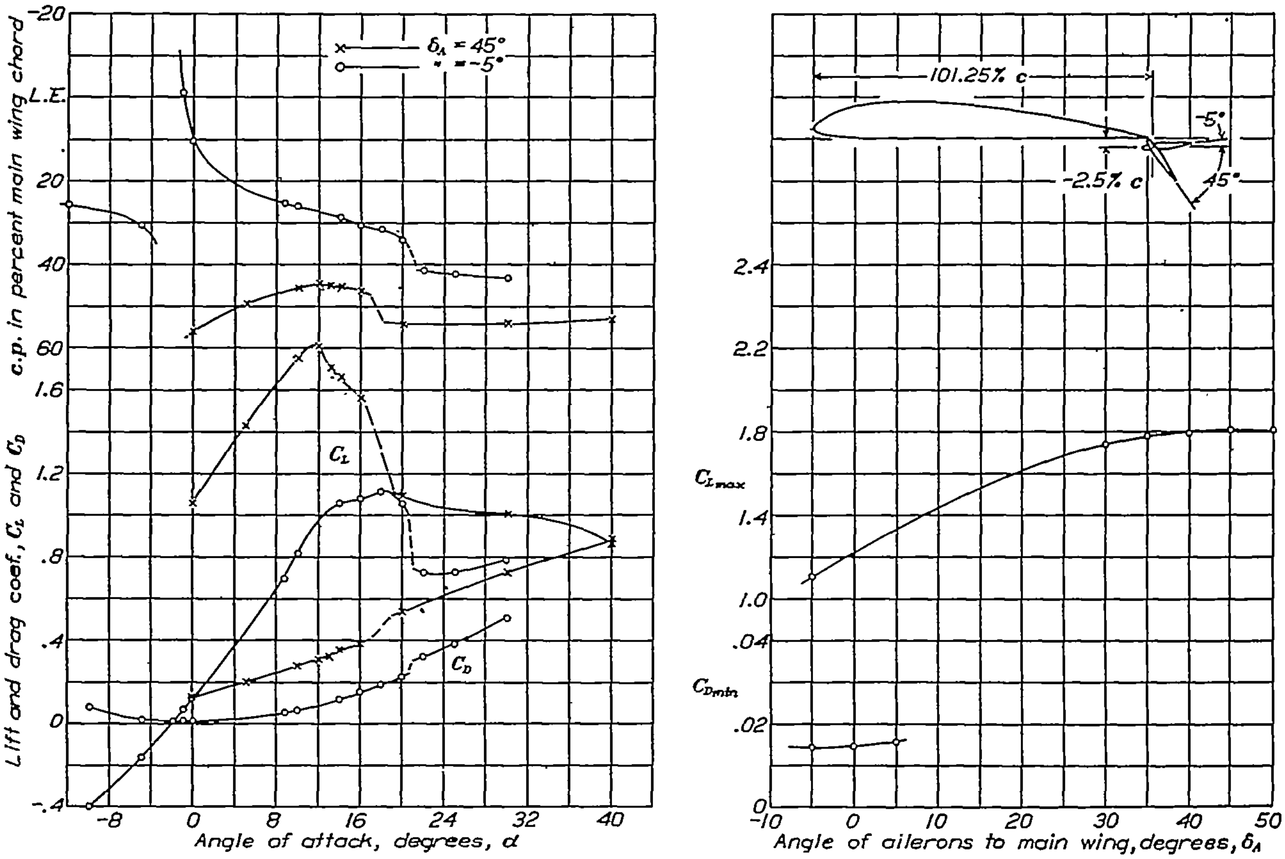


FIGURE 25.—Lift, drag, and center of pressure of Clark Y wing with symmetrical external ailerons in position 35.

if a maximum flap deflection of 20° were used and the ailerons were given an ordinary differential motion. In that case a satisfactorily light and smooth control force could be obtained with a relatively simple linkage.

Lateral stability.—Tests on factors influencing lateral stability were made only at positions 1, 6, 26, and 35. Data on the plain wing with and without ordinary ailerons are also given as a basis for comparison.

Considering first the angle of attack above which the wing tends to autorotate when the ailerons were mounted in position 1, the angles for initial instability were higher than with the plain wing. This condition held true for both the cambered and symmetrical

When the ailerons were mounted in positions 6, 26, or 35, the angles for initial instability were approximately the same as for the plain wing except when the ailerons were deflected for use as a flap in position 35. In this case, the angle for initial instability at zero rate of roll was considerably reduced, which was to be expected from the shift of the lift-coefficient curve shown in figure 22. An autorotational tendency definitely before the stall did not occur, however, with the aileron mounted in this position near the trailing edge as it did in position 1. In fact, at position 35, damping against rolling existed until the wing was definitely beyond the angle for maximum lift. When

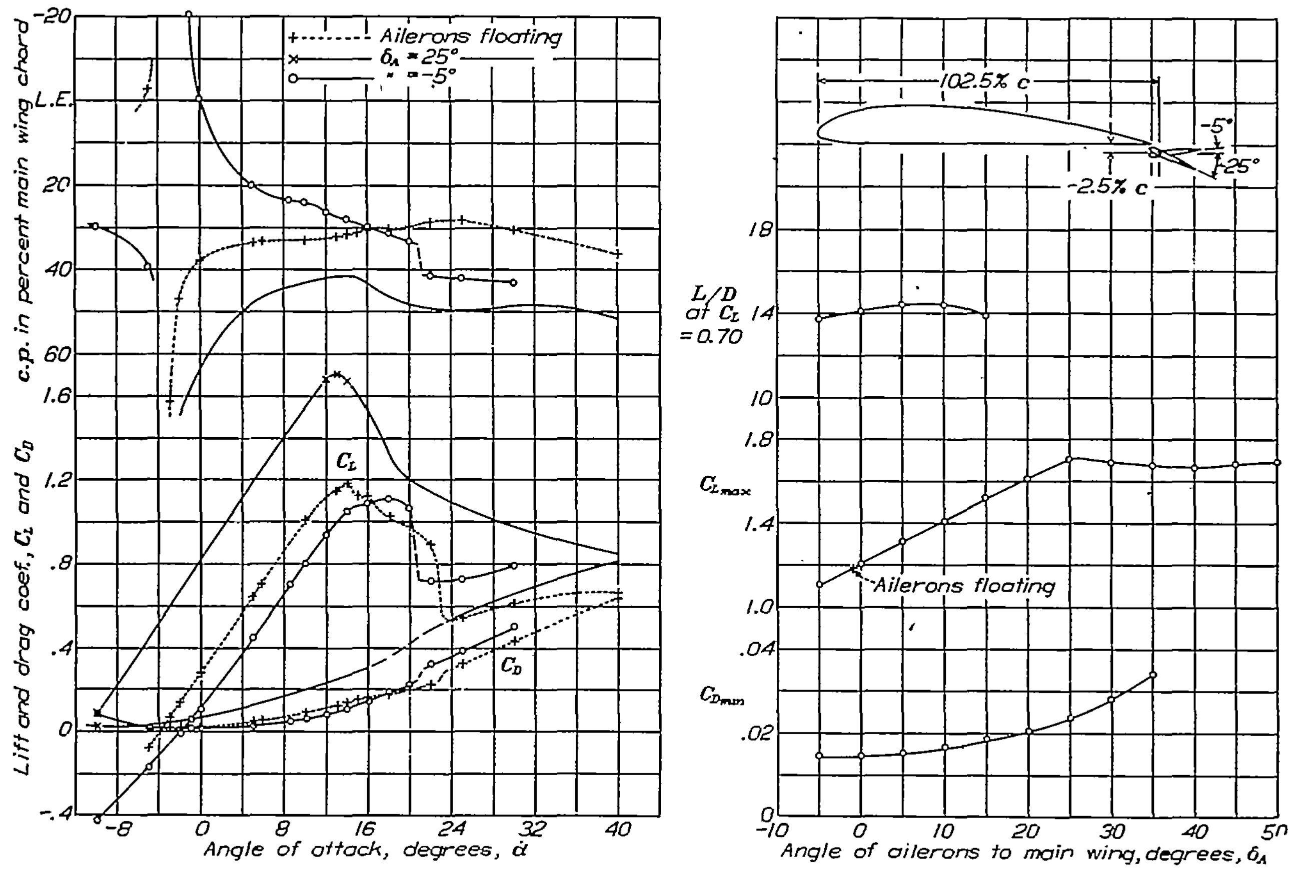


FIGURE 26.—Lift, drag, and center of pressure of Clark Y wing with external ailerons in position 37. The coordinates of all points on the curves for $\delta_A = 25°$ not marked (X) are interpolated from data obtained at $\delta_A = 20°$ and 30°.

ailerons, the highest angles being reached when the cambered ailerons were used. This delay in the angle for initial instability was due to the later stalling angle of the wing with external ailerons, but it is important to note (see fig. 20) that autorotation occurred 6° before the stall for both aileron profiles tested.

The autorotational moments at a rate of rotation such that $p'b/2V=0.05$ occurred at approximately the same initial angle of attack as that at which autorotation was self-starting. With 20° yaw the initial angle was about 3° lower with either the cambered or symmetrical airfoil in position 1 but about 6° lower with the plain wing alone.

the ailerons were mounted in position 35 and the wing was rolled, the angle for initial autorotational tendency at 0° yaw was only slightly lower but, at 20° yaw, autorotation occurred over the entire normal-flight range, as compared to beginning at about $\alpha=10°$ for the plain wing. The significance of this condition in relation to the lateral-stability characteristics of a complete airplane is largely dependent upon the fin and rudder design, dihedral, and other aerodynamic features of the airplane. In general, however, the increase in range over which the wing autorotates corresponds to the condition produced by an increase in dihedral, a change that increases the spiral stability of an airplane but makes it more difficult to maintain a yawed attitude such as might be employed in a cross-wind landing. Judging from as yet unpublished data on rolling moments due to yaw with various degrees of dihedral, the particular flap arrangement here discussed corresponds, over the normal-flight range, to about 4° of dihedral.

Maximum rolling moments due to rolling (C_λ) encountered at a rate of rotation such that $p'b/2V=0.05$ are shown at the bottom of table XXVII. The wing without ailerons showed distinctly smaller moments than the wing with ordinary ailerons at 0° yaw but

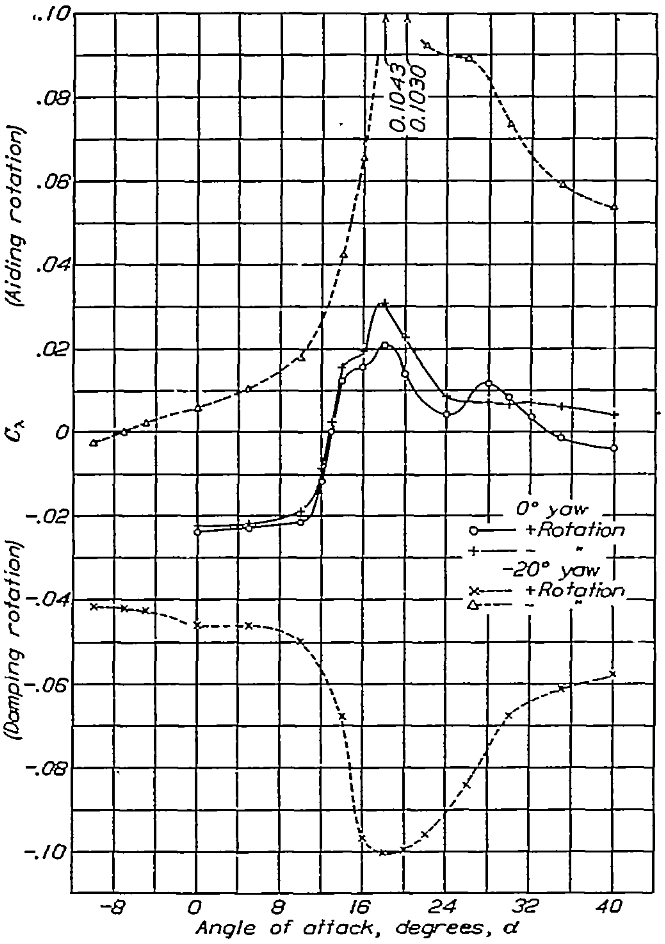


FIGURE 27.—Rolling moment due to rolling. $p'b/2V=0.05$. Clark Y wing with no ailerons.

about the same moments at 20° yaw. Maximum values of C_λ for all the positions of the ailerons tested were about equal to the wing without ailerons at zero yaw. At 20° yaw, however, the wing with the ailerons in position 1 showed a considerable reduction in unstable moments. At positions 26 and 35 smaller differences occurred, but the distinction is not sufficient to draw any conclusions therefrom.

The values of C_λ are plotted against angle of attack in figure 27 for the plain wing without ailerons and in figures 28 and 29 for the wing with external ailerons in position 35. Similar curves for position 26 vary only slightly from those for the wing without ailerons.

SIZE OF AILERONS

Tests conducted on a Clark Y wing having Handley Page tip slots of various spans (reference 9) showed that decreasing the slot to even slightly less than full span cut down the increase in lift due to the slot very materially. It was to be expected that the effect upon $C_{L_{max}}$ of external ailerons would vary with span in the same manner. Thus, where either an increase or a decrease in $C_{L_{max}}$ was obtained by use of full-span ailerons, use of less than full-span ailerons would cause only a small portion of this change. Variation of $C_{D_{min}}$ and L/D at $C_L=0.70$ with aileron span is likely to be ap-

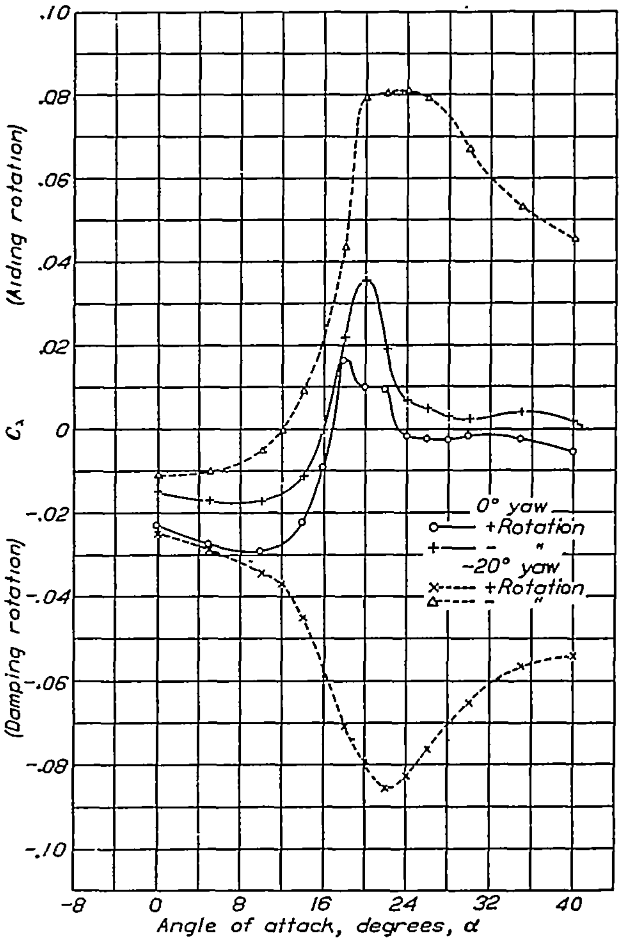


FIGURE 28.—Rolling moment due to rolling. $p'b/2V=0.05$. Clark Y wing with symmetrical external ailerons in position 35. $\delta_A=-5°$.

proximately proportional to the span of the aileron. The rolling and yawing moments obtainable with full-span ailerons would be reduced by using ailerons that extended over only the outer portion of the wing, but the reduction would be much less abrupt than the change in $C_{L_{max}}$ for the same differences in aileron span length; far example, use of only the outer half of each semispan would give a value for the moments about three-quarters of that obtainable by using the entire semispan.

The effect of changing the chord of external ailerons is more difficult to estimate, but it is expected that variations within reasonable limits associated with changes in the axis location to maintain approximately the same geometrical relation between the wing and aileron when deflected would have only a small influence on the rolling and yawing moments obtainable and on the performance characteristics of the wing.

From the preceding discussion it is apparent that, if it is necessary to use less than full-span ailerons, the greatest over-all efficiency may be obtained by placing the ailerons in a position giving good control and poor performance rather than one giving primarily good performance.

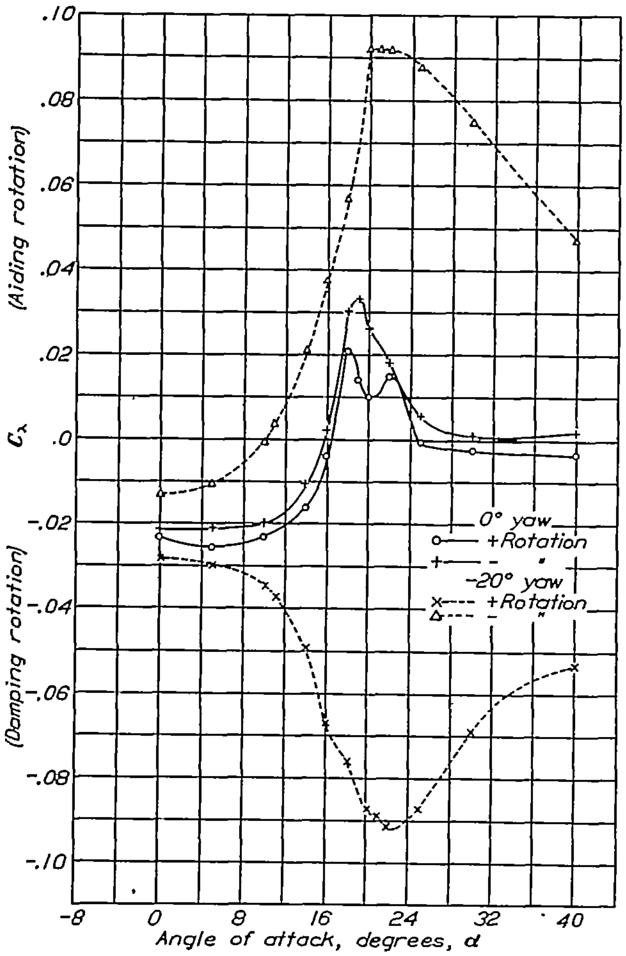


FIGURE 29.—Rolling moment due to rolling. $p'b/2V=0.05$. Clark Y wing with symmetrical external ailerons in position 35. $\delta_A=45°$.

CONCLUSIONS

The following conclusions apply specifically to external ailerons having a symmetrical profile, a chord 15 percent of the main wing chord, and a span equal to the main wing span. Position of the ailerons is specified, in all cases, relative to a point 20 percent of the aileron chord from its leading edge. The coordinates of this point relative to the leading edge of the chord of the main wing are given in percent of the main wing chord.

1. Purely from the consideration of the rolling moment obtainable at all angles of attack, the most favorable location for external ailerons was found to be 30 percent back of the leading edge and about 3 percent above the upper surface. Use of external ailerons in this position had an adverse effect on the general performance characteristics of the main wing.

2. External ailerons mounted 16 percent above the chord line at the leading edge of the main wing and using up-only deflection gave low but usable rolling moments at all angles of attack, large favorable yawing moments, and performance characteristics equal to those of the plain wing in all respects except climb.

3. Use of external ailerons mounted in the optimum position for a fixed auxiliary airfoil (27 percent ahead of the leading edge and 13 percent above the chord) did not give satisfactory control under any conditions.

4. The best position for a full-span combined flap and aileron was 2.5 percent below and 2.5 percent behind the trailing edge of the main wing. Rolling and yawing moments obtainable by deflection of the ailerons from either the low-drag or the high-lift neutral settings were not greatly different from those given by ordinary ailerons. The control linkage is likely to be complicated if full advantage is to be taken of the available rolling moments in both flap settings.

5. At any position where the principal action of the aileron is to spoil the flow over the upper surface of the main wing, up-only deflection is preferable to down-only because of the lag with the latter.

6. External ailerons did not give entirely satisfactory control and wing performance in any position tested.

Flight tests have shown that it is very difficult to design a practical control linkage which will move an aileron through a large angular deflection in one direction only (such as is necessary to obtain the maximum values of C_l' in many external aileron positions), with a smoothly graduated and reasonably light control force over the entire range of aileron deflections.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., *July 23, 1934.*

REFERENCES

1. Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack.
   I. Ordinary Ailerons on Rectangular Wings. T. R. No. 419, N. A. C. A., 1932, by Fred E. Weick and Carl J. Wenzinger.
   II. Slotted Ailerons and Frise Ailerons. T. R. No. 422, N. A. C. A., 1932, by Fred E. Weick and Richard W. Noyes.
   III. Ordinary Ailerons Rigged up 10° When Neutral. T. R. No. 423, N. A. C. A., 1932, by Fred E. Weick and Carl J. Wenzinger.

IV. Floating Tip Ailerons on Rectangular Wings. T. R. No. 424, N. A. C. A., 1932, by Fred E. Weick and Thomas A. Harris.

V. Spoilers and Ailerons on Rectangular Wings. T. R. No. 439, N. A. C. A., 1932, by Fred E. Weick and Joseph A. Shortal.

VI. Skewed Ailerons on Rectangular Wings. T. R. No. 444, N. A. C. A., 1932, by Fred E. Weick and Thomas A. Harris.

VII. Handley Page Tip and Full-Span Slots with Ailerons and Spoilers. T. N. No. 443, N. A. C. A., 1933, by Fred E. Weick and Carl J. Wenzinger.

VIII. Straight and Skewed Ailerons on Wings with Rounded Tips. T. N. No. 445, N. A. C. A., 1933, by Fred E. Weick and Joseph A. Shortal.

IX. Tapered Wings with Ordinary Ailerons. T. N. No. 449, N. A. C. A., 1933, by Fred E. Weick and Carl J. Wenzinger.

X. Various Control Devices on a Wing with a Fixed Auxiliary Airfoil. T. N. No. 451, N. A. C. A., 1933, by Fred E. Weick and Richard W. Noyes.

XI. Various Floating Tip Ailerons on Both Rectangular and Tapered Wings. T. N. No. 458, N. A. C. A., 1933, by Fred E. Weick and Thomas A. Harris.

XII. Upper-Surface Ailerons on Wings with Split Flaps. T. R. No. 499, N. A. C. A., 1934, by Fred E. Weick and Carl J. Wenzinger.

2. Weick, Fred E., and Bamber, Millard J.: Wind-Tunnel Tests of a Clark Y Wing with a Narrow Auxiliary Airfoil in Different Positions. T. R. No. 428, N. A. C. A., 1932.
3. Weick, Fred E., and Sanders, Robert: Wind-Tunnel Tests on Combinations of a Wing with Fixed Auxiliary Airfoils Having Various Chords and Profiles. T. R. No. 472, N. A. C. A., 1933.
4. Harris, Thomas A.: The 7 by 10 Foot Wind Tunnel of the National Advisory Committee for Aeronautics. T. R. No. 412, N. A. C. A., 1931.
5. Jacobs, Eastman N., Ward, Kenneth E., and Pinkerton, Robert M.: The Characteristics of 78 Related Airfoil Sections from Tests in the Variable-Density Wind Tunnel. T. R. No. 460, N. A. C. A., 1933.
6. Stack, John: Tests in the Variable Density Wind Tunnel to Investigate the Effects of Scale and Turbulence on Airfoil Characteristics. T. N. No. 364, N. A. C. A., 1931.
7. Weick, Fred E., Soulé, Hartley A., and Gough, Melvin N.: A Flight Investigation of the Lateral Control Characteristics of Short Wide Ailerons and Various Spoilers with Different Amounts of Wing Dihedral. T. R. No. 494, N. A. C. A., 1934.
8. Joyce, Temple N.: Zap Flaps and Ailerons. A. S. M. E., Trans., April 1934, vol. 56, no. 4, pp. 193–201.
9. Weick, Fred E., and Wenzinger, Carl J.: Effect of Length of Handley Page Tip Slots on the Lateral-Stability Factor Damping in Roll. T. N. No. 423, N. A. C. A., 1932.

TABLE III

FORCE TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD, N. A. C. A. 0012 AILERON, POSITION 1

R. N.=609,000 Velocity=80 m. p. h. Yaw=0°

α		−10°	−5°	−4°	0°	2°	4°	5.7°	10°	15°	20°	22°	24°	25°	26°	28°	30°	40°
	δ_A	AILERONS NEUTRAL																
C_L	0°	−0.313	−0.035	0.035	0.326	0.463	0.606	0.699	0.965	1.238	1.473	1.556	1.656	1.695	1.021	0.965	0.944	0.924
C_D	0°	.050	.0176	.0165	.021	.029	.043	.067	.127	.212	.320	.376	.434	.467	.481	.514	.550	.733
$C_{m_{c/4}}'$	0°	−.093	−.101	−.095	−.038			−.012	.014	.039	.056	.061	.064	.063	.002	.000	.002	−.003
		RIGHT AILERON DOWN. LEFT AILERON 0°																
C_l'	5°	0.004	−0.001		−0.001				0.001	0.000	0.001	0.002		0.007		0.002	0.000	0.003
C_n'	5°	−.001	.000		.000				.002	.002	.003	.002		.000		.000	.001	.000
C_l'	10°	.002	−.001		.000				.002	.002	.004	.005		−.009		.005	.001	.005
C_n'	10°	−.002	.000		.001				.003	.004	.006	.006		.005		.002	.002	.001
C_l'	30°	−.006	−.002		.007				.015	.017	.023	.050		.016		.021	.017	.017
C_n'	30°	.000	.003		.006				.011	.014	.015	.012		.009		.006	.002	.001
C_l'	50°	−.017	−.010		.005				.028	.049	.069	.074		.032		.037	.036	.028
C_n'	50°	.008	.006		.008				.016	.017	.016	.016		.011		.008	.000	.003
		LEFT AILERON UP. RIGHT AILERON 0°																
C_l'	5°	0.000	−0.003		−0.002				0.001	0.000	0.015	0.017		0.010		0.000	−0.002	0.002
C_n'	5°	.000	−.001		.000				.002	.002	.003	.002		.000		.000	.002	.000
C_l'	10°	.003	−.004		−.004				.002	.001	−.016	−.020		.010		−.002	−.006	.002
C_n'	10°	−.001	−.002		.000				.004	.004	.002	.002		.002		.002	.005	.003

TABLE IV

FORCE TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD. N. A. C. A. 0012 AILERON, POSITION 1

R. N.=609,000 Velocity=80 m. p. h. Yaw=−20°

α		−10°	−5°	0°	10°	15°	20°	22°	25°	28°	30°	35°	40°
	δ_A	AILERONS NEUTRAL											
C_L	0°	−0.300	−0.045	0.280	0.882	1.137	1.369	1.448	1.350	1.186	1.151	0.970	0.890
C_D	0°	.056	.024	.025	.112	.185	.285	.333	.445	.565	.600	.640	.710
C_l'	0°	−.001	−.004	−.004	−.008	−.014	−.021	−.023	−.028	−.060	−.056	−.053	−.041
C_n'	0°	.001	.000	.000	.004	.008	.014	.016	.023	.023	.027	.042	.036
		RIGHT AILERON DOWN. LEFT AILERON 0°											
C_l'	50°	−0.009	−0.009	−0.004	0.002	0.003	0.014	0.020	0.030	−0.002	−0.001	−0.006	0.004
C_n'	50°	.009	.010	.012	.022	.030	.036	.037	.038	.035	.034	.040	.033

TABLE V

ROTATION TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD, N. A. C. A. 0012 AILERON, POSITION 1

R. N.=609,000 Velocity=80 m. p. h. C_λ is given for forced rotation at $p'b/2V=0.05$ (+) Aiding rotation. (−) Damping rotation

α		0°	5°	10°	14°	15°	16°	18°	19°	20°	21°	22°	24°	26°	28°	30°	32°	35°	40°
YAW=0°. AILERONS NEUTRAL																			
(+) Rotation (clockwise)	C_λ	−0.023	------	−0.022	------	−0.021	------	−0.024 / −.021	−0.022 / .024	−0.022 / .028	0.010	0.012	0.019	0.012	------	0.012	------	−0.001	−0.001
(−) Rotation (counterclockwise)	C_λ	−.020	------	−.018	------	−.016	------	−.009	.029	.034	.017	.020	.025	.016	------	.012	------	.004	.002
YAW=−20°. AILERONS NEUTRAL																			
(+) Rotation (clockwise)	C_λ	−0.026	−0.026	−0.028	−0.031	------	−0.034	−0.037	------	−0.032	------	−0.014 / −.034	−0.031 / −.029	−0.024	−0.039	−0.038	−0.032	−0.028	−0.035
(−) Rotation (counterclockwise)	C_λ	−.015	−.012	−.009	−.003	------	.000	.003	------	.006	------	.030 / .007 / .042	.033 / .050	.051	.050	.047	.050	.055	.032

TABLE VI

FORCE TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD, N. A. C. A. 0012 AILERON, POSITION 1

R. N.=609,000 Velocity=80 m. p. h. Yaw=0°

α		−5°	−4°	−3°	0°	5°	6.5°	10°	14°	15°	16°	18°	20°	22°	25°	30°	40°
	δ_A [1]	AILERONS FLOATING—NEUTRAL															
C_L	0°	−0.013	0.050	0.110	0.291	0.606	0.699	0.907	1.060	1.085	1.076	1.082	1.044	1.004	0.867	0.803	0.817
C_D	0°	.018	.167	.170	.020	.041	.051	.077	.114	.126	.142	.172	.206	.240	.380	.452	.617
$C_{m_{c/4}}'$	0°	−.060	−.067	−.067	−.067	−.066	−.063	−.058	−.048	−.048	−.054	−.050	−.072	−.083	−.118	−.105	−.102
		RIGHT AILERON UP. LEFT AILERON DOWN															
C_l'	20°	------	------	------	−0.006	------	------	−0.013	------	------	------	------	−0.041	------	------	−0.020	−0.007
C_n'	20°	------	------	------	.000	------	------	.000	------	------	------	------	−.002	------	------	.006	.008
C_l'	30°	------	------	------	−.004	------	------	−.014	------	------	------	------	−.043	------	------	−.028	−.003
C_n'	30°	------	------	------	.000	------	------	.000	------	------	------	------	.000	------	------	.011	.013
C_l'	40°	------	------	------	−.002	------	------	−.016	------	------	------	------	−.046	------	------	−.030	−.004
C_n'	40°	------	------	------	.001	------	------	.000	------	------	------	------	.004	------	------	.016	.017

[1] Total deflection between ailerons.

TABLE VII

FORCE TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.45-INCH CHORD, N. A. C. A. 22 AILERON, POSITION 1

R. N.=609,000 Velocity=80 m. p. h. Yaw=0°

α		−10°	−5°	−4°	−3°	0°	5°	10°	15°	20°	22°	24°	25°	26°	27°	28°	30°	35°	40°
	δ_A	AILERONS—NEUTRAL																	
C_L	0°	−0.276	−0.032	0.090	0.120	0.344	0.706	0.985	1.245	1.498	1.580	1.655	1.686	1.709	1.733	1.030	0.990	0.903	0.849
C_D	0°	.045	.024	.191	.183	.024	.052	.138	.224	.346	.405	.465	.493	.529	.557	.539	.577	.657	.750
$C_{m_{c/4}}'$	0°	−.071	−.054	−.043	−.038	−.014	.028	.032	.054	.075	.080	.086	.086	.088	.089	.017	.017	.013	.003
		RIGHT AILERON DOWN. LEFT AILERON 0°																	
C_l'	5°	0.000	−0.001	------	------	−0.001	------	0.002	0.003	0.004	------	0.006	------	0.005	0.003	0.006	0.005	0.005	0.004
C_n'	5°	.000	.000	------	------	.000	------	.002	.003	.004	------	.003	------	.003	.003	.002	.001	.000	.000
C_l'	15°	−.006	−.007	------	------	.006	------	.009	.010	.015	------	.018	------	.006	------	.011	.004	.011	.010
C_n'	15°	.005	.000	------	------	.004	------	.006	.009	.010	------	.009	------	.007	------	.006	.003	.002	.002
C_l'	30°	−.011	−.006	------	------	.010	------	.022	.024	.043	------	.029	------	.029	------	.029	.026	.022	.021
C_n'	30°	.004	.004	------	------	.006	------	.013	.015	.015	------	.008	------	.008	------	.007	.002	.002	.002
C_l'	45°	−.018	−.017	------	------	.007	------	.035	.052	.071	------	{.084 .042}	------	.039	------	.042	.042	.031	.028
C_n'	45°	.010	.006	------	------	.008	------	.013	.015	.014	------	{.011 .009}	------	.008	------	.006	.000	.003	.003
		RIGHT AILERON UP. LEFT AILERON 0°																	
C_l'	10°	------	------	------	------	0.008	------	−0.004	------	0.004	------	------	0.016	------	------	------	−0.008	------	------
C_n'	10°	------	------	------	------	.000	------	−.006	------	−.009	------	------	−.009	------	------	------	−.005	------	------
C_l'	20°	------	------	------	------	.012	------	.002	------	.000	------	------	.014	------	------	------	.010	------	------
C_n'	20°	------	------	------	------	.002	------	−.006	------	−.012	------	------	−.014	------	------	------	−.014	------	------

TABLE VIII

FORCE TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.45-INCH CHORD, N. A. C. A. 22 AILERON, POSITION 1

R. N.=609,000 Velocity=80 m. p. h. Yaw=−20°

α		−10°	−5°	0°	10°	15°	20°	22°	24°	25°	26°	28°	30°	35°	40°
	δ_A	AILERONS NEUTRAL													
C_L	0°	−0.174	−0.031	0.313	0.891	---------	1.370	1.442	1.519	1.551	1.241	1.220	1.112	---------	0.901
C_D	0°	.050	.029	.029	.122	---------	.303	.349	.402	.444	.505	.548	.583	---------	.734
C_l'	0°	.002	.001	−.001	−.008	---------	−.018	−.023	−.027	---------	−.036	−.042	−.056	---------	−.034
C_n'	0°	.001	.001	.001	.003	---------	.013	.015	.018	---------	.021	.024	.031	---------	.037
		RIGHT AILERON DOWN. LEFT AILERON 0°													
C_l'	45°	−0.005	−0.006	−0.002	0.004	0.004	0.013	---------	0.026	---------	0.033	0.039	0.003	0.003	−0.006
C_n'	45°	.011	.010	.012	.020	.026	.033	---------	.035	---------	.035	.034	.030	.029	.038

TABLE IX

ROTATION TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD, N. A. C. A. 22 AILERON, POSITION 1

R. N.=609,000 Velocity=80 m. p. h. C_λ is given for forced rotation at $p'b/2V$=0.05 (+) Aiding rotation. (−) Damping rotation

α		0°	10°	12°	14°	15°	16°	18°	20°	21°	22°	24°	26°	28°	30°	32°	35°	40°
YAW=0°. AILERONS NEUTRAL																		
(+) Rotation (clockwise).	C_λ	−0.023	−0.021	--------	--------	−0.020	--------	--------	−0.020	{−0.019 .028}	0.018 .016	0.018 .019	0.011	0.007	0.011	--------	−0.001	−0.003
(−) Rotation (counterclockwise).	C_λ	−.021	−.018	--------	--------	−.016	--------	--------	−.014	{−.014 .027}	.026	{.024 .025}	.017	.013	.018	--------	.007	.004
YAW=−20°. AILERONS NEUTRAL																		
(+) Rotation (clockwise).	C_λ	−0.023	−0.027	−0.030	−0.031	--------	−0.033	−0.035	−0.019	--------	−0.014	−0.033	−0.034	−0.038	−0.040	−0.039	−0.031	−0.025
(−) Rotation (counterclockwise).	C_λ	−.016	−.006	−.004	−.003	--------	−.001	.002	.005	--------	.010	.031	.040	.049	.045	.044	.050	.044

TABLE X

FORCE TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD, N. A. C. A. 0012 AILERON, POSITION 3

R. N.=609,000 Velocity=80 m. p. h. Yaw=0°

α	δ_A	−5°	−4°	−3°	0°	5.6°	10°	15°	19°	20°	21°	25°	30°	40°
		AILERONS NEUTRAL												
C_L	−10°	0.001	0.066	0.133	0.322	0.700	0.945	1.193	1.360	1.379	1.341	1.193	1.135	1.010
C_D	−10°	.0170	.0164	.0168	.021	.052	.112	.197	.289	.318	.353	.474	.569	.732
$C_{m_{c/4}}'$	−10°	−.070	−.065	−.064	−.057	−.046	−.044	−.044	−.050	−.058	−.070	−.111	−.138	−.162
		RIGHT AILERON UP. LEFT AILERON −10°												
C_l'	40°	--------	--------	--------	0.015	--------	0.019	--------	--------	0.045	--------	--------	0.037	0.019
C_n'	40°	--------	--------	--------	.011	--------	.008	--------	--------	−.003	--------	--------	−.017	−.013
C_l'	70°	--------	--------	--------	.016	--------	.042	--------	--------	.058	--------	--------	.026	.040
C_n'	70°	--------	--------	--------	.019	--------	.023	--------	--------	.018	--------	--------	.004	−.011
		RIGHT AILERON DOWN. LEFT AILERON −10°												
C_l'	10°	--------	--------	--------	0.007	--------	0.029	--------	--------	0.064	--------	--------	0.047	0.023
C_n'	10°	--------	--------	--------	.006	--------	.014	--------	--------	.012	--------	--------	.003	.002
C_l'	32°	--------	--------	--------	.010	--------	.052	--------	--------	.086	--------	--------	.070	.041
C_n'	32°	--------	--------	--------	.013	--------	.018	--------	--------	.012	--------	--------	.004	.003

TABLE XI

FORCE TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD, N. A. C. A. 0012 AILERON, POSITION 6

R. N.=609,000 Velocity=80 m. p. h. Yaw=0°

α	δ_A	−10°	−5°	−4°	−3°	0°	6°	10°	15°	17°	18°	19°	20°	22°	25°	30°	40°
		AILERONS NEUTRAL															
C_L	0°	−0.279	0.001	0.063	0.128	0.323	0.702	0.913	1.152	1.248	1.282	1.157	1.152	1.118	0.986	0.910	0.695
C_D	0°	.067	.0174	.0170	.018	.023	.070	.123	.199	.239	.261	.280	.296	.333	.374	.483	.621
$C_{m_{c/4}}'$	0°	−.054	−.062	−.061	−.057	−.054	−.053	−.050	−.054	−.060	−.065	−.075	−.080	−.090	−.085	−.113	−.163
		RIGHT AILERON DOWN. LEFT AILERON 0°															
C_l'	5°	0.002 −.002	−0.005	--------	--------	0.000	--------	0.002	0.006	--------	0.020	--------	0.023	0.024	0.005	0.003	−0.002
C_n'	5°	.001	.000	--------	--------	.002	--------	.003	.005	--------	.006	--------	.006	.004	.005	−.002	.001
C_l'	15°	.001	.001	--------	--------	.006	--------	.024	.038	--------	.047	--------	.049	.054	.049	.030	−.002
C_n'	15°	.007	.005	--------	--------	.007	--------	.012	.013	--------	.012	--------	.010	.008	.002	.000	.002
C_l'	30°	−.010	.003	--------	--------	.016	--------	.050	.066	--------	.074	--------	.076	.031	.076	.054	.004
C_n'	30°	.013	.012	--------	--------	.013	--------	.016	.016	--------	.014	--------	.011	.009	.004	.001	.000
C_l'	48°	−.033	.032	--------	--------	.035	--------	.068	.084	--------	.092	--------	.092	.095	.080	.065	.004
C_n'	48°	.022	.025	--------	--------	.021	--------	.020	.018	--------	.015	--------	.013	,011	.005	.003	−.004
		RIGHT AILERON UP. LEFT AILERON 0°															
C_l'	5°	0.001	0.003	--------	--------	0.003	--------	−0.003	−0.004	--------	0.004	--------	0.010	0.003	0.014	0.018	0.000
C_n'	5°	−.002	.000	--------	--------	.000	--------	−.004	−.006	--------	−.005	--------	−.005	−.005	−.001	−.003	−.001
C_l'	10°	.004	.006	--------	--------	.005	--------	.001	.002	--------	−.001	--------	.006	.007	.028	.025	.000
C_n'	10°	−.001	.000	--------	--------	.000	--------	−.004	−.007	--------	−.008	--------	−.010	−.010	−.001	−.004	−.001
C_l'	50°	--------	--------	--------	--------	.028	--------	.034	--------	--------	--------	--------	.055	.054	--------	.043	.004
C_n'	50°	--------	--------	--------	--------	.019	--------	.017	--------	--------	--------	--------	.010	.006	--------	−.005	−.005

TABLE XII

FORCE TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD, N. A. C. A. 0012 AILERON, POSITION 6

R. N.=609,000 Velocity=80 m. p. h. Yaw=−20°

α		−10°	−5°	0°	10°	15°	18°	20°	22°	25°	30°	40°
	δ_A	AILERONS NEUTRAL										
C_L	0°	−0.274	−0.010	0.285	0.825	1.040	1.150	1.200	1.220	1.070	0.965	0.726
C_D	0°	.059	.022	.026	.114	.181	.233	.274	.320	.372	.472	.611
C_l'	0°	.001	−.003	−.006	−.013	−.020	−.025	−.034	−.039	−.062	−.075	−.055
C_n'	0°	−.002	.001	.001	.004	.008	.011	.013	.016	.022	.036	.043
		RIGHT AILERON DOWN—LEFT AILERON 0°										
C_l'	48°	−0.007	−0.005	−0.005	0.021	0.033	0.038	0.040	0.041	0.040	0.006	−0.042
C_n'	48°	.020	.022	.022	.030	.030	.031	.031	.030	.039	.030	.039

TABLE XIII

ROTATION TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD, N. A. C. A. 0012 AILERON, POSITION 6

R. N.=609,000 Velocity=80 m. p. h. C_λ is given for forced rotation at $p'b/2V$=0.05 (+) Aiding rotation (−) Damping rotation

α		0°	5°	10°	11°	14°	16°	18°	20°	22°	26°	30°	32°	35°	40°
YAW=0°—AILERONS NEUTRAL															
(+) Rotation (clockwise)	C_λ	−0.022	−0.020	−0.020	--------	−0.019	−0.010	−0.003 −.004	−0.003 .000	0.002	0.008	0.014	0.010	0.008	0.000
(−) Rotation (counterclockwise)	C_λ	−.018	−.018	−.017	--------	−.014	−.006	.002 .004	.000 .003	.006	.012	.020	.020	.016	.006
YAW=−20°—AILERONS NEUTRAL															
(+) Rotation (clockwise)	C_λ	−0.025	−0.028	−0.031	−0.032	−0.037	--------	−0.046	--------	−0.065	−0.050 −.051	−0.067	−0.068	−0.056	−0.054
(−) Rotation (counterclockwise)	C_λ	−.011	−.008	−.001	.001	.008	--------	.019	--------	.047	.072	.082	.083	.076	.056

TABLE XIV

FORCE TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD, N. A. C. A. 0012 AILERON, POSITION 12

R. N.=609,000 Velocity=80 m. p. h. Yaw=0°

α		−5°	−4°	−3°	0°	6.3°	10°	15°	17°	18°	19°	20°	22°	25°	30°	40°
	δ_A	AILERONS—NEUTRAL														
C_L	5°	0.013	0.050	0.106	0.294	0.702	0.933	1.109	1.169	1.171	1.204	1.169	0.711	0.698	0.765	0.704
C_D	5°	.021	.020	.021	.025	.056	.088	.146	.170	.182	.194	.222	.311	.364	.474	.633
$C_{m_{c/4}}'$	5°	−.062	−.063	−.062	−.059	−.060	−.062	−.063	−.065	−.066	−.068	−.085	−.117	−.123	−.145	−.163
		RIGHT AILERON UP—LEFT AILERON 5°														
C_l'	0°	--------	--------	--------	0.001	--------	0.002	--------	--------	--------	--------	−0.002	−0.001	--------	0.001	0.000
C_n'	0°	--------	--------	--------	.000	--------	.000	--------	--------	--------	--------	−.002	−.001	--------	.000	−.001
C_l'	10°	--------	--------	--------	.007	--------	.013	--------	--------	--------	--------	.026	.002	--------	.003	−.001
C_n'	10°	--------	--------	--------	.002	--------	.002	--------	--------	--------	--------	−.001	−.002	--------	.001	.001
C_l'	40°	--------	--------	--------	.044	--------	.064	--------	--------	--------	--------	.072	.070	--------	.001	.000
C_n'	40°	--------	--------	--------	.013	--------	.009	--------	--------	--------	--------	.001	−.004	--------	−.003	−.001
C_l'	70°	--------	--------	--------	.060	--------	.085	--------	--------	--------	--------	.101	.089 .037	--------	−.002	−.001
C_n'	70°	--------	--------	--------	.021	--------	.019	--------	--------	--------	--------	.010	.006 .000	--------	.000	.001

TABLE XV

FORCE TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD, N. A. C. A. 0012 AILERON, POSITION 26

R. N.=609,000 Velocity=80 m. p. h. Yaw=20°

α		−10°	−5°	−4°	−3°	0°	5.7°	10°	12°	14°	16°	18°	20°	22°	25°	30°	40°
	δ_A	AILERONS NEUTRAL															
C_L	10°	−0.368	−0.024	0.045	0.110	0.311	0.700	0.961	1.044	1.090	1.098	1.082	1.057	0.709	0.700	0.770	0.704
C_D	10°	.071	.017	.016	.017	.021	.050	.083	.103	.120	.147	.171	.211	.308	.363	.485	.620
$C_{m_{c/4}}'$	10°	−.037	−.064	−.067	−.068	−.070	−.078	−.086	−.085	−.076	−.077	−.080	−.086	−.114	−.123	−.149	−.154
		RIGHT AILERON UP—LEFT AILERON 10°															
C_l'	5°	0.012	0.011	--------	--------	0.010	--------	0.010	--------	0.006	0.004	−0.001	0.003	0.000	0.000	0.000	0.000
C_n'	5°	.001	.000	--------	--------	.000	--------	−.002	--------	−.001	−.001	−.001	−.001	.000	.000	.000	.001
C_l'	0°	.017	.016	--------	--------	.016	--------	.016	--------	.012	.007	.002	.008	.001	.000	.000	.000
C_n'	0°	.004	.002	--------	--------	.000	--------	−.002	--------	−.002	−.002	−.002	−.002	.000	.000	.000	.001
C_l'	−20°	.041	.042	--------	--------	.042	--------	.040	--------	.033	.030	.021	.019	.002	.000	−.001	.000
C_n'	−20°	.013	.008	--------	--------	.005	--------	−.001	--------	−.002	−.003	−.004	−.003	−.001	.000	.000	.001
C_l'	−40°	.059	.061	--------	--------	.062	--------	.062	--------	.058	.051	.039	.027	.005	.000	−.001	−.001
C_n'	−40°	.021	.016	--------	--------	.012	--------	.002	--------	−.002	−.002	−.003	−.002	−.008	.000	.000	.001
C_l'	−60°	.068	.069	--------	--------	.070	--------	.077	--------	.072	.062	.047	.030	.005	−.001	−.001	−.001
C_n'	−60°	.028	.022	--------	--------	.017	--------	.006	--------	.002	.001	.000	.000	.001	.000	.000	.000
		LEFT AILERON DOWN—RIGHT AILERON 10°															
C_l'	15°	0.012	0.008	--------	--------	0.008	--------	0.006	--------	0.005	0.004	0.004	0.005	0.002	0.000	0.001	0.001
C_n'	15°	.001	.000	--------	--------	−.001	--------	−.002	--------	−.001	−.001	−.001	−.001	.000	.000	.000	.000
C_l'	20°	.023	.014	--------	--------	.008	--------	.002	--------	.004	.005	.005	.008	.002	.000	.000	.001
C_n'	20°	.001	.000	--------	--------	−.002	--------	−.002	--------	−.002	−.002	−.002	−.003	.000	.000	.000	.000

TABLE XVI

FORCE TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD, N. A. C. A. 0012 AILERON, POSITION 26

R. N.=609,000 Velocity=80 m. p. h. Yaw=20°

α		−10°	−5°	0°	10°	12°	14°	16°	18°	20°	22°	25°	30°	40°
	δ_A	AILERONS NEUTRAL												
C_L	10°	0.334	−0.037	0.267	0.848	0.925	0.968	0.987	0.996	1.012	0.818	0.788	0.783	0.704
C_D	10°	.057	.021	.023	.077	.092	.105	.123	.147	.181	.301	.359	.461	.594
C_l'	10°	.002	−.004	−.007	−.009	−.013	−.021	−.031	−.051	−.069	−.083	−.086	−.081	−.050
C_n'	10°	.000	.002	.002	.004	.006	.008	.011	.013	.016	.021	.032	.044	.040
		RIGHT AILERON UP—LEFT AILERON 10°												
C_l'	−60°	0.066	0.061	0.063	0.058	----------	0.049	0.035	0.015	−0.007	−0.048	−0.063	−0.070	−0.052
C_n'	−60°	.025	.023	.018	.010	----------	.010	.012	.013	.016	.011	.023	.039	.038

TABLE XVII

ROTATION TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD, N. A. C. A. 0012 AILERON, POSITION 26

R. N.=609,000 Velocity=80 m. p. h. C_λ is given for forced rotation at $p'b/2V=0.05$ (+) Aiding rotation. (−) Damping rotation

α		0°	5°	10°	14°	16°	17°	18°	19°	20°	22°	24°	26°	30°	35°	40°
YAW=0°—AILERONS NEUTRAL																
(+) Rotation (clockwise)	C_λ	−0.023	−0.024	−0.020	−0.012	−0.004	−0.002	0.217	0.016	0.014	0.010	−0.001	−0.001	−0.002	0.000	−0.003
(−) Rotation (counter clockwise)	C_λ	−.017	−.017	−.014	−.006	.003	.007	.029	.027	.024	.013	.005	.002	.000	.002	.001
YAW=−20°—AILERONS NEUTRAL																
(+) Rotation (clockwise)	C_λ	−0.029	−0.030	−0.033	−0.039	--------	--------	−0.059	--------	−0.071	−0.076	−0.077	−0.074	−0.067	−0.054	−0.050
(−) Rotation (counter clockwise)	C_λ	−.009	−.005	.000	.018	--------	--------	.043	--------	.056	.078	.077	.074	.068	.056	.046

TABLE XVIII

FORCE TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.45-INCH CHORD, N. A. C. A. 22 (INVERTED) AILERON, POSITION 26

R. N.=609,000 Velocity=80 m. p. h. Yaw=0°

α	δ_A	−3°	−2°	−1°	0°	10°	14°	16°	17°	18°	19°	20°	21°	22°	25°	30°	40°
		AILERONS NEUTRAL															
C_L	10°	−0.033	0.035	0.106	0.164	0.838	1.036	1.055	1.062	1.064	1.032	1.024	0.995	0.670	0.692	0.752	0.708
C_D	10°	.0173	.0169	.0174	.0176	.066	.104	.134	.149	.162	.176	.191	.208	.298	.354	.474	.631
$C_{m_{c/4}}'$	10°		.000		−.001	−.011	−.018	−.032		−.040		−.052		−.090	−.104	−.124	−.142
		RIGHT AILERON UP—LEFT AILERON 10°															
C_l'	−10°				0.022	0.021						0.011				0.000	0.000
C_n'	−10°				.005	.001						−.001				.000	.000
C_l'	−20°				.032	.034						.016				.000	.000
C_n'	−20°				.007	.002						−.001				.000	.000
C_l'	−30°				.043	.045						.018				.000	.000
C_n'	−30°				.011	.004						−.001				.000	.000
C_l'	−40°				.050	.055						.024				−.001	.000
C_n'	−40°				.014	.006						.000				.000	.000
C_l'	−60°				.058	.065						.027				.000	.000
C_n'	−60°				.019	.010						.002				−.001	.000
		LEFT AILERON DOWN—RIGHT AILERON 10°															
C_l'	20°				0.006	0.004						0.004				−0.001	0.000
C_n'	20°				−.002	−.002						−.003				.000	.000
C_l'	30°				.002	−.001						.003				−.002	.000
C_n'	30°				−.004	−.004						−.004				.001	.000

TABLE XIX

FORCE TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD, N. A. C. A. 0012 AILERON, POSITION 35

R. N.=609,000 Velocity=80 m. p. h. Yaw=0°

α	δ_A	−10°	−5°	−2°	−1°	0°	8.4°	10°	14°	16°	18°	20°	22°	25°	30°
		AILERONS NEUTRAL													
C_L	−5°	−0.404	−0.161	0.010	0.069	0.124	0.700	0.815	1.056	1.081	1.109	1.055	0.723	0.727	0.786
C_D	−5°	.078	.019	.0150	.0146	.0157	.051	.065	.113	.150	.184	.223	.326	.381	.506
$C_{m_{c/4}}'$	−5°	.003	.009	.017	.018	.018	−.001	−.008	−.037	−.061	−.075	−.098	−.131	−.142	−.170
		RIGHT AILERON UP. LEFT AILERON −5°													
C_l'	−10°	0.006	0.004			0.003		0.011	0.011	0.009	0.014	0.012	0.001	0.005	0.006
C_n'	−10°	.002	.001			.001		.000	−.002	−.002	−.001	−.001	.000	.000	−.001
C_l'	−20°	.007	−.005			−.002		.005	.004	.005	.014	.004	.004	.008	.014
C_n'	−20°	.006	.005			.005		.004	.003	.002	.002	.002	.003	.002	−.003
C_l'	−40°	.011	−.003			.006		.017	.015	.014	.008	.001	.002	−.003	−.001
C_n'	−40°	.010	.010			.011		.009	.007	.006	.005	.006	.006	.007	.009
		LEFT AILERON DOWN. RIGHT AILERON −5°													
C_l'	0°	0.007	0.007			0.009		0.014	0.015	0.011	0.007	0.004	0.004	0.004	0.008
C_n'	0°	.002	.001			.001		−.002	−.003	−.003	−.003	−.002	.000	−.001	−.003
C_l'	10°	.022	.026			.033		.041	.038	.026	.016	.009	.011	.010	.019
C_n'	10°	.003	.001			−.001		−.007	−.008	−.009	−.008	−.007	−.004	−.005	−.010
C_l'	30°	.052	.071			.081		.085	.074	.041	.024	.007	.013	.014	.019
C_n'	30°	.005	−.004			−.009		−.021	−.023	−.022	−.020	−.015	−.012	−.013	−.016
C_l'	50°	.071	.086			.096		.098	.087	.045	.022	.011	.016	.014	.014
C_n'	50°	.001	−.009			−.016		−.030	−.033	−.030	−.026	−.021	−.020	−.019	−.021

TABLE XX

FORCE TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD N. A. C. A. 0012 AILERON, POSITION 35

R. N.=609,000 Velocity=80 m. p. h. Yaw=0°

α		0°	5°	10°	11°	12°	13°	14°	16°	20°	30°	40°
	δ_A	AILERONS NEUTRAL										
C_L	45°	1.058	1.431	1.752	1.778	1.810	1.712	1.663	1.565	1.092	1.002	0.864
C_D	45°	.128	.195	.278	----	.312	.326	.349	.387	.535	.725	.882
$C_{m_{c/4}}'$	45°	−.331	−.353	−.367	----	−.358	−.349	−.347	−.343	−.355	−.361	−.347
		RIGHT AILERON DEFLECTED. LEFT AILERON 45°										
C_l'	30°	0.010	0.008	0.008	----	0.008	----	0.004	−0.003	−0.004	−0.001	−0.002
C_n'	30°	−.005	−.005	−.006	----	−.006	----	−.006	−.006	−.004	−.003	−.004
C_l'	10°	.056	.056	.051	----	.051	----	.040	.016	−.004	.000	.001
C_n'	10°	−.013	−.018	−.020	----	−.021	----	−.021	−.020	−.013	−.011	−.014
C_l'	−10°	.100	.105	.102	----	.100	----	.092	.053	.025	.011	.011
C_n'	−10°	−.015	−.023	−.030	----	−.032	----	−.032	−.029	−.024	−.019	−.023
C_l'	−30°	.097	.103	.102	----	.101	----	.092	.053	.026	.013	.016
C_n'	−30°	−.008	−.016	−.023	----	−.026	----	−.027	−.025	−.019	−.014	−.020
C_l'	−50°	.100	.108	.108	----	.116	----	.096	.058	.010	.004	.011
C_n'	−50°	−.001	−.010	−.017	----	−.020	----	−.022	−.020	−.012	−.009	−.014
		LEFT AILERON DOWN. RIGHT AILERON 45°										
C_l'	50°	0.000	0.000	−0.001	----	−0.002	----	0.001	0.001	0.003	0.001	0.001
C_n'	50°	−.002	−.001	−.001	----	−.001	----	−.002	−.002	−.003	−.001	−.002

TABLE XXI

FORCE TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD, N. A. C. A. 0012 AILERON, POSITION 35

R. N.=609,000 Velocity=80 m. p. h. Yaw=−20°

α		−10°	−5°	0°	5°	10°	12°	14°	16°	18°	20°	22°	25°	30°	40°
	δ_A	AILERONS NEUTRAL													
C_L	−5°	−0.390	−0.155	0.109	----	0.727	----	0.943	1.011	1.047	1.072	0.843	0.826	0.813	----
C_D	−5°	.063	.027	.018	----	.062	----	.103	.125	.159	.203	.319	.394	.487	----
C_l'	−5°	.010	.001	−.003	----	−.008	----	−.015	−.027	−.049	−.081	−.092	−.099	−.084	----
C_n'	−5°	.001	.002	[illegible]	----	[illegible]	----	.008	.011	.014	.017	.026	.041	.048	----
C_L	45°	----	----	.962	1.280	1.570	1.648	1.669	1.656	----	1.230	----	----	1.070	0.904
C_D	45°	----	----	.114	.173	.247	.270	.290	.321	----	.530	----	----	.728	.873
C_l'	45°	----	----	−.026	−.028	−.032	−.038	−.050	−.074	----	−.120	----	----	−.093	−.062
C_n'	45°	----	----	.005	.007	.012	.015	.021	.027	----	.037	----	----	.055	.045
		RIGHT AILERON UP 10°. LEFT AILERON 45°													
C_l'	45°	----	----	0.076	0.078	0.073	0.070	0.058	0.033	----	−0.030	----	----	−0.064	−0.039
C_n'	45°	----	----	−.011	−.016	−.020	−.022	−.019	−.012	----	−.010	----	----	.018	.010

TABLE XXII

ROTATION TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD, N. A. C. A. 0012 AILERON, POSITION 35

R. N.=600,000 Velocity=80 m. p. h. C_λ is given for forced rotation at $p'b/2V$=0.05 (+) Aiding rotation. (−) Damping rotation

α		−10°	−7°	−5°	0°	5°	10°	12°	13°	14°	16°	18°	20°	22°	24°	26°	28°	30°	32°	35°	40°
YAW=0°. AILERONS NEUTRAL. δ_A=−5°																					
(+) Rotation (clockwise)	C_λ	--------	--------	--------	−0.023	−0.027	−0.029	--------	--------	−0.022	−0.009	−0.016	0.010	0.010	−0.002	−0.002	−0.003	−0.001	--------	−0.002	−0.005
(−) Rotation (counterclockwise)	C_λ	--------	--------	--------	−.015	−.017	−.017	--------	--------	−.011	.000	.022	.036	.019	.007	.005	.003	.003	--------	.004	.002
YAW=−20°. AILERONS NEUTRAL. δ_A=−5°																					
(+) Rotation (clockwise)	C_λ	--------	--------	--------	−0.025	−0.029	−0.034	−0.037	--------	−0.045	--------	−0.071	−0.079	−0.085	−0.083	−0.076	--------	−0.065	--------	−0.057	−0.054
(−) Rotation (counterclockwise)	C_λ	--------	--------	--------	−.011	−.010	−.005	.000	--------	.000	--------	.044	.079	.081	.081	.079	--------	.068	--------	.053	.046
YAW=0°. AILERONS NEUTRAL. δ_A=45°																					
(+) Rotation (clockwise)	C_λ	--------	--------	--------	−0.024	−0.023	−0.022	−0.012	0.000	0.012	0.016	0.021	0.014	--------	0.004	--------	0.012	0.008	0.004	−0.001	−0.004
(−) Rotation (counterclockwise)	C_λ	--------	--------	--------	−.023	−.022	−.019	−.009	.002	.015	.019	.030	.023	--------	.008	--------	.007	.006	.007	.006	.004
YAW=−20°. AILERONS NEUTRAL. δ_A=45°																					
(+) Rotation (clockwise)	C_λ	−0.012	−0.012	−0.043	−0.016	−0.016	−0.050	--------	--------	−0.008	−0.007	−0.100	−0.100	−0.096	--------	−0.084	--------	−0.068	--------	−0.061	−0.058
(−) Rotation (counterclockwise)	C_λ	−.003	.000	.002	.006	.010	.018	--------	--------	.012	.006	.104	.103	.099	--------	.080	--------	.074	--------	.050	.054

TABLE XXIII

FORCE TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD, N. A. C. A. 0012 AILERON, POSITION 37

R. N.=609,000 Velocity=80 m. p. h. Yaw=0°

α		−10°	−5°	−2°	−1°	0°	5°	8.5°	10°	12°	14°	16°	18°	20°	22°	25°	-30°
	δ_A	AILERONS NEUTRAL															
C_L	−5°	−0.426	−0.167	−0.003	0.056	0.105	0.443	0.700	0.796	0.934	1.050	1.085	1.106	1.062	0.717	0.725	0.791
C_D	−5°	.083	.020	.0152	.0145	.0150	.029	.051	.062	.083	.110	.148	.184	.222	.325	.385	.502
$C_{m_{c/4}'}$	−5°	.023	.019	.026	.029	.031	.025	.013	.009	−.012	−.030	−.054	−.070	−.088	−.130	−.139	−.169
		RIGHT AILERON UP—LEFT AILERON −5°															
C_l'	−10°	−0.003	0.003			0.008			0.011		0.014	0.010	0.013	0.006	0.001	0.005	0.007
C_n'	−10°	.002	.001			.001			.000		−.002	−.002	−.002	−.002	−.001	−.002	−.002
C_l'	−20°	.005	−.005			−.001			.007		.007	.007	.003	.010	.002	.012	.014
C_n'	−20°	.005	.004			.005			.003		.002	.002	.001	.000	.001	−.001	−.004
C_l'	−40°	.008	−.002			.007			.021		.020	.016	.011	.005	.001	.002	.002
C_n'	−40°	.011	.011			.011			.008		.006	.005	.004	.004	.004	.005	.004
C_l'	−50°	.010	−.002			.007			.022		.021	.018	.013	.007	.000	−.006	−.002
C_n'	−50°	.014	.014			.014			.011		.009	.007	.006	.006	.006	.006	.006
		LEFT AILERON DOWN—RIGHT AILERON −5°															
C_l'	0°	0.007	0.006			0.007			0.011		0.013	0.008	0.006	0.006	0.001	0.002	0.001
C_n'	0°	.002	.001			.000			−.001		−.002	−.003	−.003	−.002	−.002	−.003	−.002
C_l'	10°	.019	.023			.034			.040		.037	.027	.015	.012	.005	.006	.015
C_n'	10°	.003	.002			−.001			−.007		−.008	−.009	−.009	−.008	−.005	−.006	−.009
C_l'	20°	.035	.048			.060			.065		.061	.050	.030	.010	.008	.011	.020
C_n'	20°	.001	.000			−.004			−.014		−.017	−.017	−.016	−.013	−.010	−.010	−.015
C_l'	30°	.054	.071			.083			.085		.077	.058	.033	.016	.018	.013	.018
C_n'	30°	.005	−.003			−.008			−.021		−.024	−.023	−.021	−.016	−.014	−.014	−.017
C_l'	40°	.062	.078			.083			.071		.064	.047	.024	.009	.013	.013	.020
C_n'	40°	.004	−.006			−.013			−.024		−.027	−.027	−.026	−.023	−.021	−.020	−.024

TABLE XXIV

FORCE TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD, N. A. C. A. 0012 AILERON, POSITION 37

R. N.=609,000 Velocity=80 m. p. h. Yaw=0°

α		−10°	−5°	0°	5°	10°	12°	13°	14°	16°	18°	20°	22°	25°	30°	40°
	δ_A	AILERONS NEUTRAL														
C_L	25°	[1] 0.081	0.229	0.840	1.200	1.545	[1] 1.680	[1] 1.704	[1] 1.675	1.530	1.330	1.200	1.130	1.075	0.980	0.850
C_D	25°	[1] .0236	.036	.070	.127	.200	.232	.248	.265	.300	.343	.420	.495	.565	.657	.816
$C_{m_{c/4}'}$	25°	−.217	−.240	−.259	−.275	−.286	−.288	−.287	−.283	−.282	−.287	−.294	−.301	−.308	−.314	−.314

[1] Measured values. All other values interpolated from data obtained at δ_A=20° and δ_A=30°.

TABLE XXV

FORCE TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD, N. A. C. A. 0012 AILERON, POSITION 37

R. N.=609,000 Velocity=80 m. p. h. Yaw=−20°

α		−10°	−5°	0°	10°	14°	16°	18°	20°	22°	25°	30°
	δ_A	AILERONS NEUTRAL										
C_L	−5°	−0.415	−0.170	0.089	0.710	0.942	1.122	1.062	1.074	0.847	0.832	0.823
C_D	−5°	.071	.023	.018	.060	.100	.124	.160	.204	.321	.394	.491
C_l'	−5°	.007	−.003	−.002	−.009	−.014	−.027	−.048	−.078	−.096	−.100	−.086
C_n'	−5°	−.001	.002	.003	.006	.008	.012	.014	.018	.024	.039	.048

TABLE XXVI

FORCE TESTS. 10- BY 60-INCH CLARK Y WING WITH FULL-SPAN EXTERNAL AILERONS, 1.5-INCH CHORD, N. A. C. A. 0012 AILERON, POSITION 37

R. N.=609,000 Velocity=80 m. p. h. Yaw=0°

α		−5°	−4°	−3°	−2°	0°	5°	5.8°	10°	13°	14°	15°	16°	18°	20°	22°	25°	30°	40°
	δ_A [1]	AILERONS FLOATING—NEUTRAL																	
C_L	0°	−0.076	0.000	0.065	0.136	0.276	0.638	0.697	1.006	1.146	1.186	1.119	1.116	1.020	0.970	0.889	0.539	0.608	0.662
C_D	0°	.0163	.0157	.0150	.0156	.018	.044	.050	.091	.121	.140	.151	.160	.177	.199	.221	.321	.430	.634
$C_{m_{c/4}'}$	0°	−.021	−.027	−.029	−.029	−.036	−.057	−.058	−.081	−.079	−.078	−.083	−.074	−.057	−.046	−.030	−.021	−.042	−.102
		RIGHT AILERON UP. LEFT AILERON DOWN																	
C_l'	30°					.065			.069						.015			.020	.022
C_n'	30°					−.003			−.013						−.009			−.009	−.011
C_l'	40°					.086			.086						.013			.001	.013
C_n'	40°					−.007			−.019						−.006			.006	.001

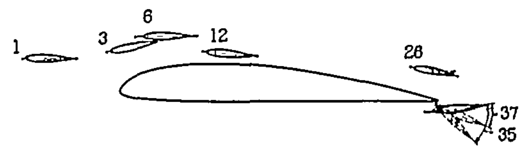
[1] Total deflection between ailerons.

TABLE XXVII

CRITERIONS SHOWING THE RELATIVE MERITS OF VARIOUS LOCATIONS FOR FULL-SPAN EXTERNAL AILERONS RELATIVE TO A 10- BY 60-INCH CLARK Y WING

Symmetrical ailerons: N. A. C. A. 0012 profile, 1.5-inch chord

Cambered ailerons: N. A. C. A. 22 profile, 1.45-inch chord



Characteristic	Criterion	Plain wing		1			3	6	12	26	35		37		
		Ordinary ailerons 25 percent chord; 40 percent semispan fixed	No ailerons	−27 percent c from L.E.; 13 percent c from chord			0 percent c from L. E.; 16 percent c from chord	10 percent c from L. E.; 20 percent c from chord	30 percent c from L. E.; 15 percent c from chord	95 percent c from L. E.; 10 percent c from chord	101.25 percent c from L. E.; 2.5 percent c from chord		102.5 percent c from L.E.; 2.5 percent c from chord		
				Cambered fixed	Symmetrical fixed	Symmetrical floating	Symmetrical fixed	Symmetrical fixed	Symmetrical fixed	Symmetrical fixed	Symmetrical fixed	Symmetrical fixed	Symmetrical fixed	Symmetrical fixed	Symmetrical floating
Aileron deflection	Neutral setting δ_A	0°	----------	0°	0°	----------	−10°	0°	5°	10°	−5°	45°	−5°	25°	----------
Relative to main wing chord	Maximum aileron deflection δ_{AL}	25°	----------	0°	0°	20°	−10°	0°	5°	20°	50°	50°	30°	30°	20°
	Maximum aileron deflection δ_{AR}	−25°	----------	45°	50°	−20°	−70°	−50°	−70°	−60°	−10°	−10°	−20°	−20°	−20°
Stalling attitude	Angle of attack at $C_{L_{max}}$	17°	18°	27°	25°	15°	20°	18°	19°	15°	18°	12°	18°	13°	14°
Wing area or minimum speed	$C_{L_{max}}$ } δ_A=neutral	1.270	1.250	1.733	1.695	1.085	1.370	1.282	1.204	1.008	1.109	1.810	1.100	1.704	1.186
High speed	$C_{D_{min}}$ } δ_A=neutral	.0160	.0155	.0183	.0165	.0167	.0164	.0170	.0202	.0103	.0146	----------	.0145	----------	.0150
Speed range	$C_{L_{max}}/C_{D_{min}}$ } δ_A=neutral	79.4	80.6	94.7	102.7	65.0	84.1	75.4	59.6	67.4	75.9	[1]124.0	76.3	[2]119.1	79.1
Rate of climb	L/D at C_L=0.70 } δ_A=neutral	15.9	15.9	13.6	10.4	13.7	13.5	10.0	12.5	14.0	13.7	----------	[3]14.4	----------	13.9
Lateral control (moments taken about wind axis).	RC' α=0° } δ_A=maximum deflection	.206	----------	.020	.015	.008	.049	.080	.204	.250	.835	.095	.782	[4].098	.311
	RC' α=10° } δ_A=maximum deflection	.074	----------	.035	.029	.018	.044	.037	.001	.082	.134	.058	.116	[4].060	.085
	RC' α=20° } δ_A=maximum deflection	.033	----------	.048	.047	.044	.042	.048	.086	.036	.022	.020	.024	[4].021	.014
	RC' α=30° } δ_A=maximum deflection	.009	----------	.042	.039	.037	.023	.047	−.002	−.002	.025	.012	.041	[4].033	.002
Lateral control with sideslip (moments taken about wind axis).	Maximum α at which ailerons will balance C_l' due to 20° yaw.	20°	----------	2°–38°	7°–29°	----------	----------	----------	----------	19°	18°	18°	----------	----------	----------
Maximum yawing moments due to ailerons (moments taken about wind axis) (+) favorable; (−) unfavorable.	C_{n_A}' α=0° } See notes for δ_A	---------- −.007	----------	.008	.008	---------- −.001	.019	.019	.021	.015	[10].001 −.016	---------- −.016	---------- −.004	---------- −.004	---------- −.007
	C_{n_A}' α=10° } See notes for δ_A	---------- −.018	----------	.013	.016	----------	.023	.017	.019	.004 −.002	---------- −.031	---------- −.031	---------- −.018	---------- −.018	---------- −.019
	C_{n_A}' α=20° } See notes for δ_A	---------- −.023	----------	[6].015	[5].017	[9].002 −.004	.018 [14]−.003	.010 ----------	.010 [10]−.002	---------- [13]−.003	---------- −.023	---------- −.027	---------- −.016	---------- −.016	---------- [8]−.009
	C_{n_A}' α=30° } See notes for δ_A	---------- −.015	----------	[8].003	[7].006	---------- −.010	.004 [14]−.017	[11].004 −.005	[11].001 [14]−.003	---------- ----------	---------- −.022	---------- −.020	---------- −.021	---------- −.021	.006 [8]−.009
Lateral stability (δ_A=neutral)	α for initial instability in rolling	19°	17°	21°	19°	----------	----------	21°	----------	18°	18°	14°	----------	----------	----------
	α for initial instability at $p'b/2V$=0.05: Yaw=0°	18°	16°	21°	19°	----------	----------	17°	----------	10°	16°	13°	----------	----------	----------
	Yaw=20°	11°	10°	17°	16°	----------	----------	10°	----------	10°	12°	−7°	----------	----------	----------
	Maximum unstable C_λ at $p'b/2V$=0.05: Yaw=0°	.048	.033	.028	.034	----------	----------	.020	----------	.029	.036	.030	----------	----------	----------
	Yaw=20°	.093	.092	.050	.055	----------	----------	.083	----------	.078	.081	.104	----------	----------	----------

[1] Computed from $C_{D_{min}}$=0.0146.

[2] Computed from $C_{D_{min}}$=0.0143.

[3] δ_A=5°.

[4] Calculated from interpolated values of C_L obtained from data at δ_A=20° and δ_A=30°.

[5 to 14] Where the maximum yawing moment occurred below maximum deflection, the deflection of the aileron which is moved the greatest amount is indicated as follows: [5]=40°, [6]=30°, [7]=20°, [8]=15°, [9]=10°, [10]=0°, [11]=−10° [12]=−20°, [13]=−30°, [14]=−40°.